Earth Stories

Course Materials for

Physical Science 110B

Brigham Young University

Instructor:

B.R. Bickmore

Table of Contents

Earth Stories—PS 110B

Credit Hours: 2
2-2:50, Tuesday, Thursday
C-215 ESC

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Office Hours: TTH 3-5
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Prerequisites

- PS 110A or decent high school physics and chemistry classes. If you haven't taken these, then you can probably get by, but plan on putting in some extra work.

Required Materials

- Lutgens and Tarbuck, *Foundations of Earth Science*, 5th ed., Prentice Hall.

Course Description

This course is meant to help pre-service elementary teachers gain the kind of deep understanding of the earth science principles needed to teach in today's elementary schools. You will accomplish this through reading, in-class activities, projects, and lab exercises.

Course Purpose

Elementary school teachers are now required to teach quite a bit of earth science to their students (much more than when I was in school.) The last earth science course most of you have probably taken, however, was in junior high school, and PS 110B is likely to be the last earth science class you will ever take. The purpose of this course, therefore, is to help you understand the earth science concepts that state and national standards mandate that elementary school students learn.

Obviously, we will be shooting for a deeper understanding than your students will need, for two reasons. 1) You are in college now. We're supposed to expect more of you. 2) STUDENTS ASK HARD QUESTIONS!!! How do I know this? Because I regularly visit elementary schools to give presentations on earth science topics, and in 2007-2008 I was the 5th-6th grade Knowledge Bowl coach at Orchard Elementary in Orem. Believe me, you won't just need to know a few science "facts." They will ask you things like, "How do they know what's in the center of the Earth, if nobody has been there?" "What is this rock I found in my yard?" "What is the difference between weathering and erosion?" "How was this rock made?" "If this rock formed deep underground, how did it get to the surface?" "If the rocks on Mt. Timpanogos show that this area was once covered by the sea, how did sea level get so high?" "Why is the Great Salt Lake so salty, but Utah Lake isn't?" The list could go on and on. Good teachers will have answers for these questions, or at least have the mental equipment to think through it and find answers. Unprepared teachers will pass the buck, and the kids will suffer.

Course Learning Outcomes

- Explain what science is, and why science is done the way it is. To do this, you will have to learn *how scientists think*.
- Explain earth science concepts in terms of fundamental physical and chemical processes.
- Explain (in general terms) the history of the Earth, or particular features of the Earth, using correct scientific vocabulary.
- Identify and debunk common misconceptions about earth science.

Student Learning Goals

Write down a few personal goals you have for what you would like to learn in this class. Please refer to them throughout the semester.

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Classroom/Homework Procedures

Each class period you will show up and sit with a group of your peers (about 5-6 people.) My hope is that you will pick a group and stick with it, so you can all get comfortable with one another. Here is the general sequence of events after that.

1. You should come to class having looked over the learning objectives listed in your course pack. You may want to even take notes right on the sheets or concept maps.
2. Someone will say a prayer.
3. 5 minutes for questions about the previous period's assignment.
4. I will introduce the topic for the day. During class, I will ask you questions designed to a) expose misconceptions, or b) get you thinking about the subject more like a scientist. Some questions you will answer via iClicker, and some you will discuss in groups and come up with free-response answers.
5. You will discuss your answers in groups and come up with arguments for the answers you chose (~3 minutes.)
6. Some of the groups will report on the arguments they came up with.
7. I will explain my take on the questions, and address any misconceptions that were revealed in the discussion.
8. There might be some other activities and in-class writing assignments sprinkled in, as well.

After class, you should proceed as follows.

1. You will look over the learning objectives for the class period you just attended to see what you are supposed to come out knowing and being able to do.
2. You will read your class notes and the assigned reading, and make sure you know/can do what the learning objectives specify. You may want to rewrite your notes in a more organized fashion.
3. You will take an online quiz on Blackboard to demonstrate your knowledge and see if there are still any concepts you need to work out.

iClickers

In class, we will be using "iClickers" so that you can vote on the answers to various questions I will pose in class, and you will spend time discussing these questions in groups. I consider this to be a very important activity, because it is perfectly possible to hear an accurate lecture on a subject, but still come away with the same misconceptions you came to class with. If you are forced to grapple with conceptual questions, and then you immediately get to see the answers, you will be put on notice that you need to listen very closely if you get the answer wrong. Likewise, iClickers give me the chance to see what *everyone* in the class is thinking—not just the students who had the guts to raise their hands.

If you haven't already, you will need to **IMMEDIATELY** register your iClicker at www.iClicker.com. However, when you are asked to give your student ID, give your BYU net ID instead of your student ID number. This will allow me to connect the results I get from the iClickers to your Blackboard account.

Participation

It is very difficult to root out misconceptions embedded in learners' minds, and that is one of the main purposes of the classroom activities incorporated into this course. As teachers, you will face the same difficulty, and your task will be impossible if you still harbor the same science misconceptions you learned in elementary school. It is not acceptable to me, therefore, to let you get away with skipping this class. For this reason, 5% of your grade will be based on attendance, and you will get your attendance points for each class period if you answer at least 75% of the iClicker questions. (Note: I am aware that if you want to cheat, all you have to do is have a "friend" take your iClicker to class. I have faith in your honesty, though, and therefore I don't worry about it.) I give you 4 class periods as "freebies," so you can forget your clicker, attend your own wedding, be sick, or whatever. If you are racking up more absences for legitimate reasons (see "excused absences" below) then you can talk to me about making exceptions.

Maybe some students skip class because they find the subject matter too easy, but in my experience, most students who skip classes do so because they don't like the subject—even if they are bombing the class! Again, given the poor state of science education in the country, I feel bound to make it hurt if you skip class.

Recommended Study Habits & Tips

The section on "Classroom and Homework Procedures" above has some good advice on how to succeed in the class, but frankly, I don't expect very many students to take what I have to say seriously. On the other hand, I figure that maybe you would take the advice of former students in this class more seriously. Therefore, I polled the PS 110B students who earned "A" grades during the Winter 2008 semester about their study habits, and compiled their answers in the section of this course pack following the syllabus. Read what they have to say!

Tips on Using the Syllabus

- Use the intended learning outcomes for the class and for each day to evaluate your progress throughout the course.
- Refer to the assignment due dates, descriptions, and evaluation criteria often.
- Use the recommended study habits to earn the grade you want.

Assessment Breakdown

Assessments	% Total Grade
Attendance/Participation	5%
Reading/Quizzes	15%
Midterm exams (2 exams, 15% each)	30%
Final Exam (comprehensive)	20%
Class Project	10%
Lab Activities/Tests	20%

Assignment Descriptions

Reading/Quizzes

After we discuss a unit in class, you will be given a reading assignment and Blackboard quiz to complete *30 minutes before the next class period*. The quizzes will have 5-15 questions each, and you will be able to use your book and notes. You will only have 30 minutes to complete the quizzes, however, so the more you have written down in notes (rather than having to search through the book,) the better. So make sure to take notes while you read! In fact, the first question on each quiz will be, "Did you complete the reading assignment, and try to satisfy all the unit learning objectives?" Once again, I am relying on your basic honesty.

Exams

You will be given 3 tests (including a **COMPREHENSIVE** final) during the semester. These are necessarily going to be multiple-choice questions, due to the size of the class, but I am trying to design them to test your ability to 1) recall key terms and concepts, 2) identify valid scientific explanations, and 3) apply key concepts so that your knowledge will do someone some good. Your exams will all be given online, on Blackboard, but they are CLOSED BOOK/NOTES. (Yes, you can easily cheat. However, the online format allows me to include things like color pictures, etc., that I could not include in a regular Testing Center format. Since

I want to make the tests into real learning experiences, I have decided not to worry about possible cheaters and focus on helping students who really want to learn.) See the Course Schedule for the dates. They will each include 50-150 multiple-choice questions. See your learning objectives for each period to find out what kinds of questions I expect you to be able to answer.

Class Project

Groups of 2-3 students will create a Mini-Lesson to be presented near the end of the semester. The presentations will be given during a REQUIRED field trip to Farrer Elementary School, 600 East 100 North, Provo. Each lab section will be assigned a set of science education standards for the Utah state core curriculum. The work of teaching the principles involved will be divided among the groups in the lab. Lesson plans for these Mini-Lessons will be turned in for a grade, and "dry run" of these presentations will be held in the lab sections before the final presentations, so that constructive feedback can be given. More information about the Mini-Lessons can be found at: http://www.geology.byu.edu/ps110b/presentation.htm, and in the Lab Schedule, which you can always download from Blackboard.

Grades

A	93-100%	**A-**	90-92%	**B+**	86-89%
B	83-85%	**B-**	80-82%	**C+**	76-79%
C	73-75%	**C-**	70-72%	**D+**	66-69%
D	63-65%	**D-**	60-62%	**E**	<60%

Course Schedule

You can download the Course Schedule from Blackboard, and if I'm feeling nice I'll hand it out on the first day of class. (Keeping it separate from the syllabus makes it so I don't have to change this document every semester.) Note: This is a 2-credit class, but for some bizarre reason, it is scheduled like a 3-credit class (2 hrs. lecture and 2 hrs. lab per week.) Therefore, to be fair to you I only run the class for 2/3 of the semester.

Course Policies

Excused Absences

I only allow make-ups for attendance points for university excused absences or illness. In other words, if you are on a sports team or in performing arts group, you can make them up. If you are sick, you can make them up. If you (or a relative, roommate, etc.) is getting married in the middle of the semester or you are leaving town to attend some family event, you will have to decide whether attending the event is more important than your attendance points.

Late/Makeup Work

If you have some kind of extenuating circumstances, talk to me about how you can make up at least some of the work you missed, but still be fair to the rest of the class.

Extra Credit

I provide a couple ways to get extra credit in the course. 1) If you do especially well with your Farrer Elementary presentation, you can get up to 2% extra credit on your final grade. 2) You can go on a field trip to Rock Canyon with your TA, take a quiz about it on Blackboard, and receive up to 2% extra credit. This is a whopping total of 4% extra credit on your final grade—the equivalent of over half a letter grade!

Academic Honesty

The first injunction of the BYU Honor Code is the call to be honest. Students come to the university not only to improve their minds, gain knowledge, and develop skills that will assist them in their life's work, but also to build character. President David O. McKay taught that "character is the highest aim of education" (The Aims of a BYU Education, p. 6). It is the purpose of the BYU Academic Honesty Policy to assist in fulfilling that aim. BYU students should seek to be totally honest in their dealings with others. They should complete their own work and be evaluated based upon that work. They should avoid academic dishonesty and misconduct in all its forms, including but not limited to plagiarism, fabrication or falsification, cheating, and other academic misconduct.

Honor Code

In keeping with the principles of the BYU Honor Code, students are expected to be honest in all of their academic work. Academic honesty means, most fundamentally, that any work you present as your own must in fact be your own work and not that of another. Violations of this principle may result in a failing grade in the course and additional disciplinary action by the university. Students are also expected to adhere to the Dress and Grooming Standards. Adherence demonstrates respect for yourself and others and ensures an effective learning and working environment. It is the university's expectation, and my own expectation in class, that each student will abide by all Honor Code standards. Please call the Honor Code Office at 422-2847 if you have questions about those standards.

Plagiarism

Writing submitted for credit at BYU must consist of the student's own ideas presented in sentences and paragraphs of his or her own construction. The work of other writers or speakers may be included when appropriate (as in a research paper or book review), but such material must support the student's own work (not substitute for it) and must be clearly identified by appropriate introduction and punctuation and by footnoting or other standard referencing.

The substitution of another person's work for the student's own or the inclusion of another person's work without adequate acknowledgment (whether done intentionally or not) is known as plagiarism. It is a violation of academic, ethical, and legal standards and can result in a failing grade not only for the paper but also for the course in which the paper is written. In extreme cases, it can justify expulsion from the University. Because of the seriousness of the possible consequences, students who wonder if their papers are within these guidelines should visit the Writing Lab or consult a faculty member who specializes in the teaching of writing or who specializes in the subject discussed in the paper. Useful books to consult on the topic include the current *Harcourt Brace College Handbook*, the *MLA Handbook*, and James D. Lester's *Writing Research Papers*.

Preventing Sexual Harassment

Title IX of the Education Amendments of 1972 prohibits sex discrimination against any participant in an educational program or activity that receives federal funds. The act is intended to eliminate sex discrimination in education. Title IX covers discrimination in programs, admissions, activities, and student-to-student sexual harassment. BYU's policy against sexual harassment extends not only to employees of the university, but to students as well. If you encounter unlawful sexual harassment or gender-based discrimination, please talk to your professor; contact the Equal Employment Office at 422-5895 or 367-5689 (24-hours); or contact the Honor Code Office at 422-2847.

Students with Disabilities

Brigham Young University is committed to providing a working and learning atmosphere that reasonably accommodates qualified persons with disabilities. If you have any disability which may impair your ability to complete this course successfully, please contact the Services for Students with Disabilities Office (422-2767). Reasonable academic accommodations are reviewed for all students who have qualified, documented disabilities. Services are coordinated with the student and instructor by the SSD Office. If you need assistance or if you feel you have been unlawfully discriminated against on the basis of disability, you may seek resolution through established grievance policy and procedures by contacting the Equal Employment Office at 422-5895, D-285 ASB.

Study Habits of A-Students in PS 110B

In the past I have given students advice about how many hours per week they should be studying for this class, how to study, etc., but I don't think very many of them listened. I can understand why—it's been a while since I was a student, and sometimes professors just don't realize how long their assignments take, or how students' learning styles differ from our own. I decided, therefore, to poll the students who earned "A" grades in PS 110B during the Winter 2008 semester, and then pass along what they had to say about what it took to succeed in the class. Several of them responded to the poll, and gave what I think are very helpful answers. You will find that different students come to the class with widely varying backgrounds and abilities in science, and so there is no one formula for success in the class. If you are serious about succeeding, however, perhaps the best advice would be to start out near the more zealous end of the spectrum of study habits indicated here, and then ease off later, if you feel comfortable doing so.

How many hours per week did you spend OUTSIDE of class/lab studying the course content?

Summary: The A-students spent widely varying amounts of time outside of class studying the course content, but the average was probably somewhere around 4-5 hours per week.

Note from Dr. Bickmore: The BYU Undergraduate Catalog (2007-2008) explains,

> ***The expectation for undergraduate courses is three hours of work per week per credit hour for the average student who is appropriately prepared; much more time may be required to achieve excellence. These three hours may include one hour of lecture plus two hours of work outside class, three hours in a laboratory with little outside work, or any other combination appropriate to a particular course.***

Since this is a 2-credit class that we run like a 3-credit class for about 2/3 of the semester, that means you should expect to put in about 9 hours per week while the class is running. You spend a total of 4 hours in class and lab per week, which means that an "average student that is appropriately prepared" should expect to spend about 5 hours per week studying outside of class. This is only a 100-level class, however, so I think it is appropriate that it takes an average of 4-5 hours outside of class to actually get an A (i.e., to "achieve excellence.")

A-Student #1: I probably spent about an hour reading/studying for each quiz we took, and then another hour for each chapter making note cards and rereading material. Then for the tests, I would study from the note cards and concept maps.

A-Student #2: I'm not sure how much time I spent outside of class. Reviewing for lectures, I usually did little more than read the chapter. As I tend to soak up information easily, this may not be standard. I spent more study time preparing for the rock and mineral final

A-Student #3: Outside of class I spent about 3 hours a week. This was mostly used in reading the material and going over the notes from class.

A-Student #4: I probably spent 2-3 hours per week studying the course content.

A-Student #5: The amount of time I spent outside of class varied—I spent however much time it took to get things done. On average it was probably about five hours, and a couple more around the time of tests.

A-Student #6: I spent about one to two hours per chapter of the textbook. I read each chapter and recorded the most important information in a notebook. For the reading I focused my attention on the information you covered in class.

A-Student #7: I spent a lot of time out of class reading the chapters and as I read I wrote definitions and key facts on the period sheets you handed out. Writing notes as I read always helps me remember things more, and when it came time for a test I already had all my notes written down to study.

A-Student #8: I spent about 4-5 hours outside of class studying/reading each week for the quizzes... etc.

A-Student #9: I spent about three hours per week outside of class studying the course content.

A-Student #10: I spent as many hours as I needed to get the coursework done and to understand it. Something I recommend for students is to do whatever it takes. I spent several hours reading and taking notes for each quiz. For the lab, I spent several hours a week going in every other day for the rock final. It takes time, but it is worth it when you understand everything.

A-Student #11: I probably spent 5-7 hours outside of class, just doing the reading and taking quizzes. When I was reviewing for tests I would try to do so all week before the tests, which was an extra 4 hours.

A-Student #12: I spent at least 4-6 hours outside of class studying. Four hours for regular weeks and 6 when there was an exam.

A-Student #13: I probably spent about 4-5 hours outside of class studying during a normal week.

A-Student #14: I spent about 2 hours for every assignment doing the readings to prepare for the quiz. So when we had two assignments in a week, I would spend about four hours.

A-Student #15: I studied about 1-3 hours a week (including the reading) depending on the work load of the week.

A-Student #16: Probably about 3-4 hours. This included doing the reading and the quizzes.

A-Student #17: I did about three to four hours outside of class studying the reading that we had that night, taking quizzes, reading for lab, looking over lecture notes, etc.

A-Student #18: For every chapter we had to read I spent about 3-4 hours reading and taking notes. Then, before tests, I spent another 2-3 hours going over the material.

A-Student #19: I probably spent about three hours to do each reading assignment. I studied about six hours for each test. I printed all of the slides that were posted online and I reviewed those before I took the quizzes. I also took notes in class even though I printed the slides. I noticed that a lot of people didn't do that but I think it helped me to remember the concepts better and focus more in class.

A-Student #20: I spent at least double the amount of time each week out of lab and class studying the material. Just doing the readings and taking the quizzes were not enough. Going over the material covered in class helped a lot.

When you studied, did you use the concept maps I gave you? If so, how did you use them?

Summary: All of the A-students used the concept maps, but they used them in various ways. Some just looked over them a few times to make sure they understood the concepts and connections. Others went so far as to take detailed notes on the maps. A couple students also said that, at first, they didn't understand how helpful the concept maps would be, but later found out how valuable they are.

A-Student #1: Yes, I used the concept maps. I basically just read over them a few times to make sure I knew how everything was related. As soon as I understood it, I moved on.

A-Student #2: I used the concept maps to review before I took a quiz or a test. I just read over them once to refresh my memory and make sure I understood the main concepts.

A-Student #3: The concept maps were a huge help. I didn't use them before the first test and did poorly on it. I reviewed them and then tried to start at the beginning and go through them without looking. Along with the concept maps I went over the slides from the class.

A-Student #4: I did use the concept maps. I would just read them and make sure I understood everything on them. Many times they cleared up something I had been confused about.

A-Student #5: I didn't use them at the beginning, but about half way through I found that they were very useful for reviewing material after I had read it, and the best way to memorize information.

A-Student #6: I loved the concept maps. It tied everything together for me. When reviewing for the tests, I built on to the concept maps by putting all the information I knew about each concept bubble.

A-Student #7: Yes, I always used the concept maps. First I would study the terms and then I would visually link them together by using the concept maps.

A-Student #8: I definitely used the concept maps! They helped me a ton! They were great for studying for the tests and even the quizzes.

A-Student #9: I used the concept maps as a tool to review my reading and notes. They actually helped a great deal.

A-Student #10: I definitely used the concept maps you gave us. They helped a lot. I would read through the chapter and take notes first. Then I would go back and look at the concept maps and compare them to the notes I took and what information I understood while reading. It helped a lot.

A-Student #11: I did use the concept maps when I studied, and I would read over them several times, making the connections on the map in my head.

A-Student #12: I did use the concept maps…these are a gift, and they are critical to understanding the principles without having to memorize a bunch of unrelated facts. I also redrew the maps on a whiteboard and acted as if I was teaching students. I talked out loud while I was drawing and practiced, practiced, practiced. I did this both when I was alone, and with family/friends. Teachers always learn more than students!

A-Student #13: I used the concept maps only as a review tool and to understand the connections between the different concepts between chapters in the class. I sometimes used them to take notes on and to narrow my focus of studying the chapters.

A-Student #14: I used the concept maps after I had done the reading and learned the terms. The concept maps were helpful reinforcers of what I studied in the textbook.

A-Student #15: I loved the concept maps! I used them mostly to review for test and to connect the different ideas together so the "bigger picture" made more sense. Now that the course is over I think that it would be more effective to have used them more throughout than just a review.

A-Student #16: Yes, I used them a lot. They really helped me understand how things worked together. I kind of used them like a self-given quiz. I would cover up part of the concept map and say... "hmmm....the crust consists of what material?" (or whatever the question was) and then I would think of the answer in my head. Then I would uncover the circles I was covering and make sure that the arrow from the crust pointed to the words I was thinking of. I hope that made sense a little bit :)

A-Student #17: When I studied for tests I did use the concept maps. I looked over the concepts and made sure I could explain each concept to someone else and made sure that I know how they correlated to what we discusses in lab and lecture.

A-Student #18: Yes. I looked over them and made sure I understood WHY each item was connected.

A-Student #19: I did use the concept maps when I studied. I liked to study them after I did the reading because it helped me to tie everything together and see the big picture. I also used them to study for the tests because they had the important information that we needed to know.

A-Student #20: I definitely used the concept maps. They helped me a lot more than I thought they would. When I studied them, I took each bubble and formed sentences in my mind about how it connected to other things on the map. I made sure I understood everything on those maps because many quiz and test questions came from the maps.

When you studied, how did you use the unit sheets I gave you (with the learning outcomes, terms/concepts, etc.? Did you look at them before class, before you read, as you read, etc.?

Summary: All but one of the A-students used the unit sheets extensively, but in different ways. The consensus was that the unit sheets are invaluable for helping students focus their attention on the points the instructor wants them to learn, rather than on less important details.

A-Student #1: I actually didn't use the unit sheets very much. What is going to be on the test is pretty predictable, so I didn't bother to look at those sheets.

A-Student #2: I read over them before I did the readings, and sometimes reviewed the points as I read or after to make sure that I knew the material.

A-Student #3: : As I studied I would make sure that I could go back and explain what the learning outcomes were. Usually I would do this aloud to myself or to my roommate. It is more important that you can explain it to someone than it is you can think about it.

A-Student #4: I looked at the unit sheets before I read, as I read, and used them to study for the tests. It was also helpful to look at them and fill them out during the class lectures.

A-Student #5: I read through the entire unit sheet after reading the chapter, before taking the quiz, to ensure that I knew the information, and actually write the answers out and discussed them with a couple of friends when reviewing for tests.

A-Student #6: The unit sheets were like a study guide for me. Without them, I feel like the chapters of reading would have been really intimidating, but the unit sheets gave me a direction on what I should study the most.

A-Student #7: I would look at them before I read and then as I read I would follow along the unit sheets to make sure I was reading everything I should be. These sheets were very helpful for the quizzes and studying for tests.

A-Student #8: When I studied, I would make sure I knew everything on the unit sheet. I would go and find the info from the book, past quizzes, or your PowerPoints. I looked at the learning outcomes before I read the chapter and then I looked for the answers throughout.

A-Student #9: I would look at the unit sheets before reading, to see what I was supposed to learn.

A-Student #10: I would look at the unit sheets before I read, then took notes while I read from the learning outcomes, terms/concepts, etc, and then I would go back through and study what I should have taken out of each chapter.

A-Student #11: I read the learning outcomes, etc., before I read and as I was reading, and then I would look over them after reading to make sure that I covered all of the concepts.

A-Student #12: I read the unit sheets BEFORE reading the chapters. I also tried to stay ahead by reading the chapters BEFORE class. Class was much easier to understand and more interesting when I already had the concepts in my brain.

A-Student #13: I used the unit sheets as a review before taking each chapter quiz so that I could make sure I understood each key concept.

A-Student #14: I used the unit sheets to prepare for the tests and the quizes. I would look at them as I read to make sure that I could find the key words and write them down. I also looked at them when I was done to remember the important points. I usually would go back and write a short definition by the key words.

A-Student #15: When I studied I did use the unit sheets, they were especially helpful when studying for the tests. I sometimes read over the unit sheets before class, I did read over them before I did the reading, and sometimes afterward to clarify what I was supposed to have learned.

A-Student #16: I used those a lot. They were especially helpful. I would just go through each learning outcome and make sure that I could answer the question. Then I would look at the terms and see which learning outcome they fit under. I looked a them before I read and then went over them briefly after. The times I used them the most was when I was preparing for quizzes and tests. There was so much information in each chapter, but those sheets helped to narrow down the information.

A-Student #17: I looked at the unit sheets as I read, and took notes as I read and remembered what we discussed in lecture and I went to lab and looked for the correlations there and asked any questions that I had, and my TA was always willing to help if I had any questions.

A-Student #18: I wrote out the terms and learning outcomes on sheets of notebook paper. Then, as I read, when I came to each answer or term, I wrote down what I needed to know. After I finished reading, I looked back and tried to find what I was missing. Then, I studied from these notes.

A-Student #19: I looked at the unit sheets after I did the reading. I wrote out the answers to the questions and then studied them before I took the quizzes. They also really helped when I was studying for tests.

A-Student #20: I always read over the unit sheets before I read because then I knew what to look for when I was reading. During and after I did the reading, I would fill out the learning outcomes. This helped a lot because it would become cemented in my brain. I then made sure I could intelligently talk about the terms/concepts. Do this and you will do great in the class.

Did you take detailed notes based on the unit sheets, or did you just sort of look at them and keep the points in mind as you studied? If you took notes, how detailed were they?

Summary: The note-taking habits of the A-students varied widely, but the most common strategy was to take notes based on the unit sheets. Most of the students' notes seem to have been fairly detailed.

A-Student #1: My notes were not very detailed. What I did was print off the PowerPoint presentations and study from those. During class, if something was said that wasn't on the PowerPoint slide, then I wrote it down. Other than that, I wasn't big on note taking.

A-Student #2: No, I didn't take notes. I just soaked up information as I read, and I usually didn't have to even remember the points as I read because they tended to be things I picked up on my own. Again, when it comes to learning, I am like a sponge, so this may not be standard and a lot of people may have to do more.

A-Student #3: I took notes on the unit sheets, it was much easier to review for the test if all the notes were located in one place instead of having to take ideas from the unit sheet to my notes. The notes I took were not detailed; I tried to write down the main points and focus on concepts rather than memorizing details.

A-Student #4: I would just write down the answers to the questions on the unit sheets. I did not take notes other than that.

A-Student #5: I took notes according to the outline of the book (sometimes more detailed than others depending on the type of info and how much I felt I already knew on the subject), and then in my head went through the points on the sheet. Before tests I took notes on the unit sheets that weren't extremely detailed, but enough that it would help jog my memory on the subject.

A-Student #6: I made sure that I covered everything on the unit sheets and made detailed notes about them. But to be successful in understanding the material, I read the information, circling what was covered on the unit sheets. That solidified the information for me. My notes were pretty similar to the text in the book. My notes were just a way to distinguish the most important information at easy access.

A-Student #7: Yes, I took tons of notes on the unit sheets. I had notes written everywhere explaining concepts and definitions. They were definitely detailed—detailed enough so that I could understand what the concept was and be ready to answer any question concerning that concept.

A-Student #8: I didn't take way detailed notes, but I would write down the basic ideas and then write down what page numbers discussed it or what lecture slides did so I could go back and study for the test.

A-Student #9: When I studied, I would review my notes from class the previous day (which were fairly detailed), then read through the period sheet to see what concepts I was supposed to focus on. I would then read the chapter completely through, then review by looking at the concept maps (which actually helped a great deal). I would then take the daily quiz right away.

A-Student #10: I took detailed notes based on the unit sheets. The concepts on the unit sheets covered the main points in the chapter. So I would read through the question and take notes on everything that fell under that topic.

A-Student #11: I wrote down every question on the unit sheets on a separate sheet of paper, then answered them using all of my resources. I used as much detail as possible, so that none of the points were left out. My in-class notes focused on things you said that were not on the PowerPoints.

A-Student #12: After reading the chapter, I typed out all the questions and then answered with as many as details as I could. I composed charts, graphic organizers, or even my own concept maps, if necessary. This provided me with a great study guide for the exams.

A-Student #13: I used the unit sheets for taking notes in class some of the time, but never in just reading the chapter. I took very detailed notes in lectures and most of the time had the reading done before the assigned lecture.

A-Student #14: I took detailed notes on the readings and incorporated the things from the unit sheets that we were supposed to know. I would also answer the questions on the unit sheet itself.

A-Student #15: I took pretty detailed notes, I do not think that they needed to be so detailed, especially because you post the power points. I took note on a seperate sheet of paper but I think that it woudl be more effective to take notes on the period sheets/concept maps.

A-Student #16: I only took notes a couple of times on the sheet. When I did take notes, I just put key words under the learning outcomes and just put the page number where the definitions of the terms could be found. This way when I was going back through them before the test I did not have all of the answers in front of me, but if I was stumped and needed to look up the answer I had the page number written down.

A-Student #17: I just kinda looked at the notes, and wrote down what I didn’t know, and things that I wanted to remember and then I the power points online before I took the quizzes and exams.

A-Student #18: I took somewhat detailed notes. For my notes, I wrote down as much as I needed so that I would read it later and understand what I had written and why I had written that.

A-Student #19: I took notes on the unit sheets but they weren't too detailed. I just wrote down the main points after I read and then made sure that I was able to explain them in more detail.

A-Student #20: My notes on the unit sheets consisted of answering the learning outcomes. If I had the sheet during lecture, I would expand on the bubble sheet, which helped a lot. My notes weren’t extremely detailed, just enough to trigger the concept that I had learned.

Of all your study activities, which things do you think were keys to your success? That is, what did you do that your friends who didn't do so well neglected? (You may include activities not mentioned above, if you like.)

Summary: The most common themes were 1) focusing on the concept maps and unit sheets, and 2) explaining the concepts to oneself, friends, or study partners. The act of explaining solidified the concepts in their minds.

A-Student #1: My note cards were the key to my success. Just because that is how I learn the best. But I also discovered something else that really helped. I studied with a friend who had already taken physical science, and understood it. He made me explain everything to him-not just define terms or spew back answers, but actually explain why or how things happened. It really helped me solidify concepts and fully understand them.

A-Student #2: I'm sorry, but I don't know; this is one of the questions that is difficult for me to find an answer to.

A-Student #3: I think the most important study activity was to use the concept maps. I took notes on them in class and from the book. Studying was much easier because I knew what Dr. Bickmore wanted and could focus on concepts rather than details.

A-Student #4: The things that really helped me were doing all the reading and filling out the answers to all the unit sheets. Also looking at the concept maps and going to all the lectures helped me understand things I maybe had been confused about.

A-Student #5: Studying with a couple other people before tests really helped me, as in my opinion it made it more enjoyable and forced me to spend the amount of time needed on studying. It also brought insight and viewpoints that I may not have been able to see on my own.

A-Student #6: Just focusing on the text as closely as I did was key to my success. I read it to actually learn the information, not to just scrape by. I had to read it as if I really wanted to know what was in there. The class time was important for me as well.

A-Student #7: The thing that led to my success was filling out the unit sheets. I took the time to make sure I knew what everything meant on the paper and knew it so well that I could explain it to myself.

A-Student #8: I think the biggest things that helped me succeed were the unit sheets/outcomes and the concept maps. And it made a huge difference to do well on the quizzes and find the answers to the learning outcomes throughout the reading because then i understood the material better and I did well on the quizzes. And since I did well on the quizzes and went back and studied those before the tests, I knew most of the answers on the tests!

A-Student #9: The most important thing to my success was making sure I understood all of the concepts discussed in class. Reading the chapter completely was also very important. Giving 100% in labs was also important. For the rock final, I made my own review sheet compiling all the information I had about the rocks and pictures I found on the internet of them. That was also very important to my success. I know I couldn't have succeeded without actively learning about the rocks for myself.

A-Student #10: I took the time studying. I did not try to cram it all in at one point before the final or tests. I understood it a lot more by taking a few hours every other day learning the information. It definitely helped on the tests and I was not as stressed as some I saw.

A-Student #11: I studied with one other person, as well as on my own. I also took advantage of all of the resources available to me, because that way I wouldn't miss any information.

A-Student #12: The concept maps were a big key—I used them to REALLY understand the material. I visited the rock lab often to practice identifying the samples, going in at least once a week during the 3 weeks before the exam. The week before the test, I went in 2-3 times for practice. We asked your TA to set up a practice run, and made 3x5 cards for rock and mineral identification. I referred to other textbooks from geology courses that are in the lab, and looked on the Internet for images of the rocks and minerals, so I could see a variety of samples. I also used the CD that came with the textbook, which has some great pictures and animations, and I took the practice tests that are included. Finally, I looked at the world around me and tried to make up scientific stories for what I saw.

A-Student #13: I believe the keys to my success were my very detailed lecture notes and making sure to read each chapter as thoroughly as possible to understand all of the concepts before taking quizzes and coming to class. Also, I found it very important to read the labs beforehand and to study a lot on my own time in the lab before the rock identification final.

A-Student #14: The thing that helped me the most was getting with a couple of friends to study together. We would go over the unit sheets and then all give our answers to make sure we were on the right track. I worked hard and prayed harder. I also think it helped that we could look at the notes while taking the quizzes.

A-Student #15: Using the concept maps and the unit sheets for review and paying attention in class really made the difference for me. I like the subject matter and that also helped. It also helped that when I had questions I asked you about them.

A-Student #16: The TA reviews were very helpful, but I think that the thing that helped me the most was to just go through all of the unit sheets. They were my main study tool. Oh, and I studied with a friend. This helped me a lot. I know that sometimes when you get together with a friend you tend to just talk, but we really got down to business and usually what I didn't know, she knew and what she didn't know, I knew. Putting our thoughts together was the best thing we did.

A-Student #17: The concept maps, power point slides, and reading were all really key to my success in the class. And other things like just going to class and lab, and really listening and being active in the lecture and what was going on. I really came to this class with an open mind and understood everything in class really well.

A-Student #18: The key to my success was listening in class, taking notes in class, reading the chapter, taking good notes on the reading, and actually looking at all my notes afterward. My friends who did not do so well didn't fully understand things because they either did not pay attention in class or they did not study.

A-Student #19: I think the most important thing that I did was pay attention in class. Although that sounds overly simple it made a big difference. I always heard people in my lab talking about how they would do other things during lecture and they were the ones that seemed to have more difficulty understanding things that we discussed in class. I think it also helped that I tried to study before the quizzes so that I did not have to take time to look up answers.

A-Student #20: One thing that helps is to actually STUDY. I was amazed at how many of my fellow students did not put in the time or effort of learning the material. I was even more amazed when they wondered why they did not do well on tests. Just attending the class is not enough! You have to put in some extra time. Before I took each test, I would meet with a study group and go over the learning outcomes. We would talk about each one until we knew we could answer any question thrown at us. I also went over the power point slides because a lot of the test is from in class material. And if you need help with a concept it is very important to ask someone to explain it who does understand.

Introductory Essay

Why Stories?

You may be wondering about the strange title of this course packet. If this is a science class, what does that have to do with *stories*? But hopefully by the time you complete this course, you will have found out that the problem is not the title, which is wonderfully descriptive and accurate. Rather, the problem is that most people have a much too narrow view of stories, and a hopelessly sterile and boring view of science.

What a sad state of affairs! *Stories* are a big part of what makes us human, and if we never come to appreciate the full scope of human storytelling, I think we miss something that draws us together to make astounding things possible. Think of it. When we want to influence others to vote the way we do, buy or avoid certain products, invest in new companies, join religions, join the military, fight enemies, be kind to enemies, give us lighter jail sentences, give others tougher jail sentences, etc., etc., what do we do? We tell stories. And if they are particularly powerful stories—stories that just ring true—they can change the world. Where would we be if Plato had never written his dialogues (fictional conversations about philosophy,) or Jesus had never told his parables? What if nobody ever told the story of Rosa Parks refusing to move to the back of the bus? Or what if Adolph Hitler's Nazis had never blamed all of Germany's problems on the Jews? We would certainly be in a different place than we are now.

Most people will agree that modern science has allowed us to do astounding things, but they usually think of science as a bunch of facts that scientists have "discovered." Certainly scientists do discover new facts, but it is only when they combine scientific facts with scientific *stories* that science becomes a powerful force. Yes, I'm saying that scientists *rely on* things that they *make up*. So actually *doing* science requires considerable creativity, which is why professional scientists generally can't believe they actually get paid to do their jobs!

Why then is the country so desperate to recruit more people to go into science and engineering? Part of the problem is that actually *doing* science and learning science in the classroom are usually such different things. When you are in a science class, you typically aren't discovering anything really new, and you are usually expected to come up with particular answers, even when you perform "experiments." Therefore, most people end up thinking that science is a bunch of facts that scientists discover and students memorize. Even if you learn both scientific *facts* and *stories*, it is hard to tell them apart. This issue is often clearer for real scientists, because we don't have pre-determined explanations for everything we observe. Therefore, it is easier for us to separate observations from the stories we make up to explain them.

We can't be satisfied with this state of affairs here, because this is a course for pre-service elementary teachers. You will soon be teaching science to droves of kids. What will you do to help them understand what science is really about, even when you can't fully replicate the experience for them in the classroom? This is a tough question, but I am confident that, whatever answers you come up with, the first step you must take is to get it straight in your own mind what science is all about.

Once you understand what science is all about, you can become part of it. I don't mean that you will all become professional scientists—just that when you understand what science is all about, you are in a position to look into scientific claims yourself to decide how far you should trust them. You can decide which scientific stories you want to incorporate into your own view of life, and use them to decide between possible courses of action. You can use these stories to persuade others to see things your way.

Learning Earth Stories

As you learn some of the stories scientists tell about the Earth, we will do several things to help you understand them the way scientists do.

- We will complete a unit on the nature of science that is couched in very plain language.
- We will take time to reflect about which parts of what you learn can be considered facts, and which are stories.
- We will take time to let you go through the process of making up scientific stories. At least, we will try to get as close as we can to the real process.

Is This Class Relevant to My Life?

Some students come into this class a little unhappy. They don't like science, and they don't understand why the university administration is making them take it. "Even if I will have to teach science in elementary school," they say, "I already know enough science for that." However, times are changing. State and national curriculum standards are emphasizing science more and more, so that some of you might be shocked by what you will be expected to teach in elementary school. And even if you have down everything that you are supposed to teach, you will find that *kids ask lots of questions*. Finally, you will find that many elementary school science textbooks and lesson plans that are out there actually *contain blatant errors*. You will have to be prepared to recognize these.

So be afraid. The fact is that we don't have time to cover all the science you will need to teach at a depth sufficient to prepare you well for what you will face in the classroom. Some students are laboring under the delusion that they will finally learn what they will need to teach when they take El. Ed. 363, "Teaching Science in Elementary School." However, the professors who teach this class tell me that it is all about *methods*, and that when you take that class they expect you to have *already learned* the science content knowledge you need. Where do they expect you to have learned the content? You guessed it—in your required physical science and biology courses. But the fact is that you have probably never taught in an elementary school, and you don't know exactly what to expect (even if you think you do,) so it is hardly surprising that some students harbor these kinds of misconceptions.

I don't have the expertise to teach you how to teach elementary school science, but my experience has been that students who never see the relevance of this class will never really engage with it. They may cram enough into their heads to pass the tests, but they will soon forget it. They will be unprepared for their careers. Therefore, in this class we will do a couple things along the way to help you see the relevance of this class to your lives.

- You will be given examples of state and national curriculum standards that show how much you will really be expected to teach.
- We will visit an elementary school, where you will teach 5-minute science mini-lessons on Utah Core Curriculum topics. This is not meant as a substitute for you later training in science teaching methods, but as a means of helping you see 1) how hard it is to teach science to elementary school kids, and 2) how fun it can be.

Science as Storytelling

Version 4.2 (March 3, 2007)

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What is Science?

Much of our modern culture revolves around something called "science." Governments want "scientific" analysis of various problems to guide policymaking. News reports detail the latest "scientific" studies about human health. People worry about whether their religion conflicts with "science." But what is science? This turns out to be a complicated and controversial question, and whenever we try to come up with a really precise definition, we end up calling some activities "science" that we would rather exclude, or excluding some activities we would like to include (LAUDAN, 1996). For example, some people distinguish science from other activities by noting that scientists perform experiments. However, some sciences aren't particularly experimental, e.g., it is hard to imagine astronomers performing experiments on stars that are millions of light-years away. On the other hand, astronomers do collect and record observations, even if these cannot properly be called "experiments." Is the collection of observations of the natural world the defining feature of science? Apparently it isn't, since astrologers have been observing and recording the motions of heavenly bodies for millennia, and most people would not classify astrology as science. Scientists typically go on to explain their observations by creating theories that might be used to predict or control future events. However, astrologers also explain their observations by creating theories, and they certainly try to use them to predict things (OKASHA, 2002, pp. 1-2)! Furthermore, there is a certain breed of physicists, called "string theorists" who have not yet come up with a single testable prediction, but that does not keep them from being classed with the other scientists in the university physics departments where they work.

Even if it isn't easy to come up with a precise definition of "science," however, most people would agree that, in general, science does involve collecting observations about the natural world and coming up with explanations for them that might help us predict or even control the future. Therefore, we could propose a loose definition of science like the following.

> *Science is the modern art of creating stories that explain observations of the natural world, and that could be useful for predicting, and possibly even controlling, nature.*

It may bother you that we used the word "stories" instead of "explanations," "theories," or "hypotheses" in our definition. It might be a bit shocking to think of science as a kind of "storytelling," because we are accustomed to thinking about science as *factual*, whereas storytelling sounds so… *fictional*. After all, people have always told stories to explain natural phenomena, e.g., the ancient Greeks explained the daily rising and setting of the sun using the story of Apollo riding his fiery chariot across the sky, but nobody would call such stories "science" in the modern sense. However, we chose the word "stories" to emphasize the idea that the explanations scientists come up with are not themselves facts. Scientific explanations are always subject to change, since any new observations we make might contradict previously established explanations. The universe is a very complicated place, and it is very likely that any explanation that humans come up with will be, at best, an approximation of the truth. Albert Einstein emphasized the point that scientific explanations are not facts when he remarked that they are "free creations of the human mind, and are not, however it may seem, uniquely determined by the external world" (EINSTEIN and INFELD, 1961, p. 32) In other words, scientific explanations are creative products of our minds—stories—not facts that we "discover."

Another point that may trouble you about our definition of science is that we haven't yet gotten rid of the astrologers. A prominent philosopher of science put it this way: "The difference between science and other endeavors that seek explanations of why things are the way they are can be found in the sorts of standards that science sets itself for what will count as an explanation, a good explanation, and a better explanation" (ROSENBERG, 2000, p. 21). In order to help you understand why things like astrology (or history, or any number of other fields of study that could fit our loose definition) are not considered "science," we must explain the kind of standards scientists set for themselves when developing their stories.

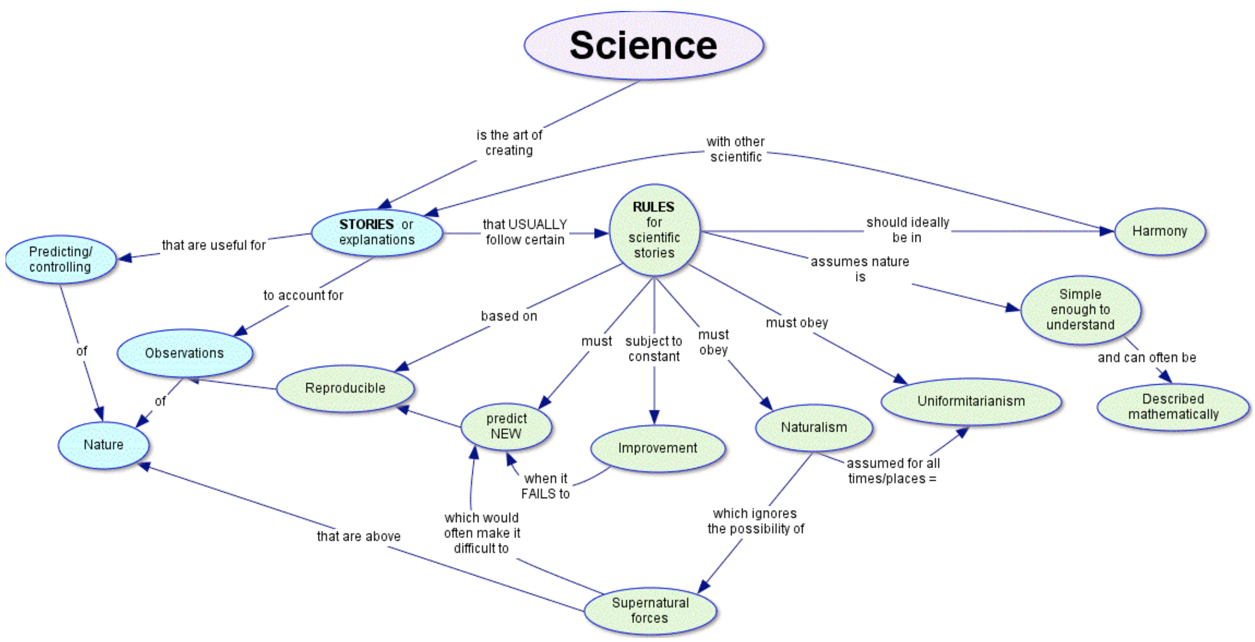

Figure 1. Concept map of the definition of science given here.

Rules for Scientific Storytelling

Just like any literary genre, scientific storytelling follows certain rules that set it apart from other types. History, historical fiction, realistic fiction, and fantasy, for example, are all types of storytelling that follow different rules regarding how closely bound they must be to the documents, experiences, and artifacts we consider to be acceptable evidence for how life was and is really like. And of course, we have to make rules about what we consider acceptable evidence—whom to believe when sources disagree, when to dismiss eyewitness accounts as impossible, what different kinds of archaeological artifacts mean about how people lived, etc.

However, it is important to realize that rules are chosen, not because no others are possible or because they are infallible guides to "Truth," but for convenience in attempting to accomplish certain goals. Remember that science is the art of creating explanations for natural phenomena that could be *useful* for predicting, and possibly controlling, nature. What kinds of rules could be made to make science more useful in this way?

Rule #1: Reproducibility

Our first rule has to do with the kind of observations that are acceptable as a basis for scientific stories.

> *Rule #1: Scientific stories are crafted to explain observations, but the observations that are used as a basis for these must be reproducible.*

For example, a chemist might perform an experiment in her laboratory, and make up a story to explain her observations. If this story is to even be considered as a scientific explanation, another chemist should, in principle, be able to make the same observations when performing an identical experiment. (This doesn't mean all these observations actually will be reproduced by other scientists—only that they *could* make the same observations if they wanted to go to the trouble.) If a paleontologist creates a story to explain how life on earth has changed over time, based on fossils he has found in various rock layers, another paleontologist ought to be able to find the same kinds of fossils in those layers. Even an astronomer who observes something strange and fleeting happening in the night sky will immediately call his colleagues at other observatories and ask them to train their telescopes on the same location. Of course, since scientific observations are supposed to be reproducible, scientists try very hard to make their observations as carefully as possible.

Note well, however, that it isn't the *story* that is reproducible, but the observations upon which the story is based. One cannot expect our paleontologist to reproduce how life has changed on Earth over millions of years in some laboratory. For one thing, most students would not want to spend such a long time in graduate school!

There are very good practical reasons for this rule, e.g., people have been known to be tricked into thinking they see things that aren't really there, or even to hallucinate. Sometimes people tend to "see" what they expected or wanted to see, or even lie. Should we accept someone's personal experience as "data" that has to be explained by science? Clearly that would open up a can of worms, and most scientists wouldn't want to deal with it.

As practical as this rule is, on the other hand, it is possible that it could be a limitation on science, especially in cases where someone observes something that happens only infrequently. For example, "falling stars" are frequently observed streaking across the night sky, but it is relatively rare for them to be observed in such a way that they can easily be connected with the meteorites that are sometimes found on the ground. In the eighteenth and early nineteenth centuries, reports of "stones falling from heaven" were met with extreme skepticism among scientists, because this wasn't possible according to the prevailing theories about the make-up of the heavens. When a meteorite fall was reported by two Harvard scientists, Thomas Jefferson responded, "I could more easily believe that two Yankee professors would lie than that stones would fall from heaven" (WATSON, 1945, pp. 172-173).

In essence, the rule that observations must be reproducible to be "scientific" narrows the field of "facts" that science must explain to experiences that are, in principle, transferable from person to person. Inner religious experiences, strange phenomena that only ever occur to single observers (e.g., UFO abduction stories,) and even extremely rare (and therefore sparsely attested) phenomena are ruled out as acceptable data for anything but psychological studies. This is not to say that such observations must be hallucinations or lies. Rather, this is simply the scientist's way of dealing with the fact that people are not always reliable witnesses.

Questions for Thought/Discussion:

1. Just because an observation isn't reproducible, it does not follow that it is false. However, do you think Rule #1 is still a good idea for the practice of science, or is it too limiting? Please explain your answer.

2. What if a scientific observation turns out later to be incorrect? Does that necessarily mean the scientists who made the observation did something wrong? Or could it simply mean that they were unlucky, didn't know exactly what to look for, misinterpreted what they were seeing, etc.? Please explain your answer.

Rule #2: Predictive Power

Scientific stories are usually called "hypotheses" or "theories." For some people, these words imply that scientific stories nearly have the status of facts, while for others, they only imply a hunch or guess. Perhaps the truth lies somewhere in between these extremes, and a more realistic viewpoint can be gained by considering our second rule for scientific stories.

> *Rule #2. Scientists prefer stories that can predict things that were not included in the observations used to create those explanations in the first place.*

When scientists first create a story, they try to explain as many observations as possible. However, there is no way of being sure that they have considered all possible explanations, so these initial stories are only considered as educated guesses. We call these educated guesses "hypotheses." A hypothesis is a sort of "*if… then*" statement. That is, *if* the explanation is true, *then* certain observations should follow (SCOTT, 2004, pp. 12-13). A good hypothesis will not only explain the observations already collected, but also predict new things that have not been observed. If some of these new predictions can be tested, then we have a way to see if our story can hold up. Once a story has successfully predicted many new observations, scientists start suspecting that it might be on the right track, and start calling it a "theory" instead of a hypothesis. Therefore, even if some scientific stories are guesses, they are at least educated guesses (hypotheses.) And even if we cannot really say that scientific stories are "the Truth," some of them (theories) have successfully predicted so many things that we think it is reasonable to believe they are at least on the right track (KITCHER, 2001).

Another example should serve to show that the *truth* of a story is not the issue when we are deciding whether a story is *scientific*. In the 19th century the great British scientist, Lord Kelvin, suggested that the sun might be a glowing ball of liquid, formed as meteorites coalesced by gravitational attraction and generated heat from friction, etc. If this were true, Kelvin reasoned, it ought to be possible to calculate the sun's age, based on estimates of its annual heat loss. He estimated that the sun had been losing heat for a maximum of 100 million years (THOMSON, 1862). Further research into the frequencies of light waves emitted by molten meteorites might also have served as a test of the predictive power of Kelvin's story. Now, it turns out that scientists since Kelvin have come up with much better ideas about what the sun is, and how its heat is generated, and these new explanations can account for many more observations than Kelvin's. For example, the light waves emitted by the sun are not characteristic of molten meteorites, and radiometric dating techniques seem to support the idea that life has existed on Earth for much longer than 100 million years. In fact, heat generated by radioactivity in the Earth had not been discovered when Kelvin made his calculations, and so he failed to account for it (ORESKES, 1999, pp. 48-51). In other words, Kelvin's explanation is now considered to be flatly wrong because its predictions failed, and it did not take into account radiogenic heat. However, it is still considered a *scientific* explanation, because it generated predictions that weren't originally used in the creation of the explanation. This kind of prediction allows science to go forward, rather than getting stuck in a rut.[1]

To this end, scientists accord special value to stories that are *mathematically precise*. Lord Kelvin, you will remember, was able to calculate an absolute upper bound for the age of the Sun, and posited a relatively precise account of the kind of material from which the Sun might be composed. This kind of precision is valuable because it offers a larger target at which other scientists can shoot. In other words, if a story that generates precise, testable predictions happens to be blatantly wrong, it should be relatively easy to shoot it down and move on.

Although some "scientific" explanations don't immediately produce predictions that we can test (remember the "string theorists,") and vary widely in degree of precision, it is easy to see why scientists *prefer* precise, testable stories. That is, if we allow too many explanations that cannot be tested in any way, then it becomes harder to decide whether to prefer one story over another.

Rule#3: Prospects for Improvement

In order to fully understand why scientists prefer testable predictions, one must first come to the realization that science is not about establishing "the facts," once for all, but about a *process* of weeding out bad explanations for the facts we collect and replacing them with better ones.

> *Rule #3. Scientific stories should be subject to an infinitely repeating process of evaluation meant to generate more and more useful stories.*

It turns out that there is no set method for scientific investigations, contrary to what you may have learned in junior high. Scientists can obtain inspiration for their stories in any number of ways, all of which involve considerable creativity, inspiration, or blind luck, and it isn't always clear by reason alone which of a number of competing stories should be favored. However, a basic process for much of what passes for "science" can be outlined as follows.

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[1] Not only that, but prediction becomes part of the success story of science. "The power of prediction," Thomas Huxley wrote, "is commonly regarded as the great prerogative of physical science" (Huxley, 1903, p. 10). What he had in mind is that scientific prediction is widely regarded as much more reliable than, say, religious prophecy or psychic precognition. One need only recall the public surprise that accompanied the 1758 appearance of Halley's comet. Comets had always elicited wonderment, but this time much of the wonderment stemmed from the *accuracy* of Edmund Halley's prediction, which enhanced the status of Newtonian science.

1. Scientists make observations about the natural world.
2. Scientists come up with explanations that can explain these observations, or at least the ones that we are most sure about, or seem most important.
3. Other consequences of these explanations are evaluated, and scientists come up with ways to observe whether some of those predictions are true.
4. Scientists then make these other observations to test their predictions.
5. If the predictions work out, then the original explanation may be kept. If the predictions do not work out, then scientists do one of three things.
    a. They throw out their initial explanation, and try to come up with another one that explains all (or at least most) of their relevant observations.
    b. They slightly modify their original explanation to account for the new observations.
    c. They ignore the new observations that do not fit with their explanation, assuming there must be something wrong with the observations. Then they either go on as if nothing had happened or try to improve the observations.
6. Whether they keep the original explanation, or go with another one, scientists always return at this point to Step #3, and keep repeating steps 3-6 over and over again.

The hope is that following this iterative process will help scientists come up with better and better stories to explain the natural world. What do we mean by "better," you ask? In general, a "better" story explains more observations and/or generates more predictions. In other words, it is more useful and amenable to further testing. Other factors may be involved, however. For instance, a scientist may prefer one theory to another because it seems more simple, or elegant. Sometimes scientists give greater credence to observations that were collected by scientists with whom they are personally familiar, or who come from the same country (ORESKES, 1999, pp. 51-53). Thus, scientists should never assume that our favorite stories represent "The Truth," because one can never tell whether an even better explanation will pop up next week. However, by tying their stories to real observations of the natural world, scientists hope to at least come up with explanations that are *realistic*, even if they are not exact representations of reality. We try to make our stories progressively "less wrong," even if we can never tell when we have gotten them exactly right (GROBSTEIN, 2005).

Indeed, we claimed above that scientists are perfectly capable of ignoring some observations that conflict with their established explanations. Why would they do such a thing? The fact is that sometimes observations go wrong—instruments do not work correctly, experiments are contaminated, and people can be deceived in what they think they see. Furthermore, the world is a complicated place, and even if a few observations seem to conflict with an explanation, it may still be mainly correct. And if it isn't immediately apparent how to fix the theory, that's no reason to throw out an otherwise perfectly good explanation. However, if observations that don't fit a scientific story keep piling up, rather than being successfully explained away, scientists begin wondering whether they ought to look harder for a better story (KUHN, 1996).

Consider the example of Galileo Galilei (1564-1642.) In his time, the geocentric (Earth at the center of the Universe) astronomy that was in fashion at the time was in trouble—a number of observations were very difficult to explain with this kind of theory. To overcome some of these problems, Copernicus had proposed that the Sun is at the center of the Universe, and everything else revolves around it in circular orbits. Galileo used a telescope to produce observations that he then advertised as supporting the Copernican theory. For example, he could show that the brightness of the planets changed through the year, which was predicted from the Copernican idea that the Earth should be at different distances from the planets at different times of year. However, the magnitudes of some of these variations were not nearly large enough to be explained by Copernicus's model. Also, many people who looked through Galileo's telescope distrusted it, because although it seemed to work well when pointed at objects on the Earth, optical illusions (such as double-vision) were noted when it was pointed toward the heavens (FEYERABEND, 1993, pp. 86-105). Clearly, the Copernican theory had problems of its own, and many of them were not solved for decades, or even centuries, as the Copernican theory was adjusted to accommodate things like elliptical, rather than circular, orbits and better theories of optics were developed. So why did it quickly become the dominant explanation of the motion of heavenly bodies, even in the face of contradictory evidence? Perhaps the answer is that even if the Copernican theory had problems, its adherents saw the *general idea* of a sun-centered Universe as more promising than the idea of an Earth-centered Universe, and so they were willing to try to work out those problems. It turns out that in this case their hunch was right, and even if our ideas about how the Universe is structured are now quite a bit different than the Copernican model, we can look back and say that the Copernicans had one or two key ideas that turned out to be indispensable.

The idea that we hope to get across here is that, at least in our opinion, the way scientists generate and improve their stories is pretty reasonable, even if it isn't exact and involves considerable guesswork. We certainly can't expect this kind of method to generate "Absolute Truth" on the first, second, third, or millionth try. But when we constantly try to improve our stories by testing and altering them to accommodate more observations, they are pretty much guaranteed to become more "useful." And as they become more and more successful at explaining and predicting more and more things, we at least have some justification for suspecting that maybe they do have some connection with the ultimate truth about how things work.

Questions for Thought/Discussion:

3. Even if there is no exact "Scientific Method" that is a sure road to the truth, do you think the way scientists go about their work is reasonable, given our human limitations? Why, or why not?

Rule #4: Naturalism

The kind of human limitations just discussed are not the end of the story, however. It turns out that scientists also deliberately impose certain limitations on their craft for practical reasons, even beyond the limitation that observations be reproducible.

> *Rule #4. Scientific explanations do not appeal to the supernatural. Only naturalistic explanations are allowed.*

When we speak of "naturalistic" explanations, we mean explanations that appeal only to "laws of nature" that operate in a regular fashion. For example, unsupported objects near the surface of the earth always seem to fall downward. We can use this "law of nature" to explain many things, including the directions in which rivers travel, the transport of sediment toward the ocean, etc. On the other hand, "supernatural" explanations appeal to the possibility that there might be forces above the "laws of nature" that can momentarily suspend those laws. For example, we might call the observation that people die and their bodies decay a "law of nature," but the Christian *New Testament* explains the claimed sightings of Jesus after his death by teaching that Jesus was resurrected. If this really happened, it seems unlikely to have been the result of the everyday operations of "laws of nature."

Looking back to some of the examples already discussed, it is clear that the explanation of the sun that included the Greek god Apollo is ruled out from the start, whereas Kelvin's explanation is not. Whereas the Apollo story involves a supernatural being, Kelvin only appealed to natural causes, such as the gravitational attraction between meteors and heat generation by friction. He said he favored his explanation of the sun's heat because "No other natural explanation… can be conceived" (THOMSON, 1862).

This brings us to a rather odd problem. That is, many scientists believe in Judaeo-Christian, Muslim, and other concepts of God and spirituality along with most of the rest of the world. Many of them even believe that "supernatural" events have occurred. And yet, by the year 1800 it was very rare for scientists to introduce the supernatural into scientific explanations, until now it is essentially unheard of (Davis and Collins, 2002). For example, Lord Kelvin not only believed in a Christian concept of God, but he even used his estimate of the age of the sun to show that there could not possibly have been enough time for life on Earth to have evolved from lower forms, as Charles Darwin suggested. He went on to propose that a relatively young solar system ruled out organic evolution and this, in turn, implied an intelligent Creator. Here he did not use the supernatural to *explain* how life on Earth appeared—he merely argued that the naturalistic explanations that had been proposed so far were deficient. And yet, Kelvin used a naturalistic explanation of the sun to make his argument. If Kelvin believed that God supernaturally generated life on earth, then why would he feel compelled to stick to "natural" explanations when offering a scientific account of the origin of the sun?

There are three practical reasons for sticking to naturalistic explanations in science. First, supernatural explanations tend not to generate precise new predictions. Not only does this stop the scientific enterprise in its tracks, but it isn't very useful. That is, supposing the sun is Apollo's chariot, what can we then do with that information? The stories about Apollo do not specify whether his horses leave giant droppings, or anything else that might help us determine whether this explanation of the sun is any more likely than others. Science operates by observing *regularities* in nature, but supernatural beings like Apollo might decide to change the natural order at any moment, and how could we predict when or why that would happen? Second, it is usually very difficult to place limits on which supernatural explanations are acceptable. For example, if it is acceptable to say that the sun is Apollo's chariot, then why not Odin's shiny helmet? Both of these points can be overstated, however. It might well be possible for supernatural explanations to generate new predictions—even some that could easily be tested—but in order for this to be so we usually must know something in advance about the supernatural agent in question. For example, if we say that God created the world, we can generate predictions about what the world is like only if we know something about what God *could have* and *would have* done during the Creation. And this brings us to our third reason for sticking to naturalistic explanations. Since different groups ascribe different attributes to God and other supernatural agents, if we allowed supernatural explanations in science we would end up with various versions of Christian, Muslim, Hindu, Buddhist, and Jewish science, to name but a few. In pluralistic society, and in an age when science is a big-money, publicly funded enterprise, most scientists would prefer that we all just try to come to some sort of compromise, for the moment, and that compromise entails keeping the supernatural out of scientific stories.

Another example of the usefulness of a naturalistic approach to science is the story of the ancient Greek physician, Hippocrates. In Hippocrates' day, illness was often attributed to the anger of the gods, and that sort of thing. In that case, a physician's job was to invoke the aid of the gods (usually Asclepius, Apollo's son) to heal the sick person. Hippocrates challenged this practice, not because he did not believe in the gods, but because he thought that the physicians of his day were often using the gods as an excuse for their own ignorance of the causes of disease. If, on the other hand, diseases were *mostly* the result of natural causes, one might often find natural cures (RUBENSTEIN, 2003). This sort of pragmatic attitude is very common today, even among deeply religious people. That is, when people are seriously ill, they usually check into the hospital, even though they might also pray for divine help.

On the other hand, even if the supernatural isn't allowed in scientific explanations, individual scientists may still use their religious views or other inner experiences in the creative process. For instance, Albert Einstein frequently used to muse about how "the Old Man" (referring to his impersonal concept of God) would have done things. However, when it came to his published scientific explanations, "the Old Man" never made an appearance. The Belgian scientist Friedrich Kekulé hit upon the idea that the benzene molecule has a ring structure after having a dream where a snake tried to swallow its own tail, but went on to test this idea using scientific methods (OKASHA, 2002, p. 79). In the creative process, anything goes, so long as a naturalistic account can be given later.

It should always be remembered that scientists don't allow God and other supernatural agents into their stories *only* because there are practical reasons not to, rather than because we can't. Furthermore, just because we can come up with a naturalistic explanation for something, it doesn't follow that the explanation is *true*. As discussed above, we can never be sure that we have hit upon the one and only possible explanation for our observations, and we can never be sure that more observations will not contradict our stories.

Once these points are clear, it should be apparent that once in a while, there will be conflicts between science and various religious viewpoints. If we do not allow the supernatural to play any part in scientific explanations, how can we expect them to always be in harmony with religious philosophies that specifically claim there are supernatural influences on the natural order? Occasional conflicts would seem to be inevitable, and therefore such conflicts should not come as a shock to anyone.

Questions for Thought/Discussion:

4. Naturalism assumes that the world works in a regular, predictable manner, with no supernatural interference. Do you think this is always, mostly, sometimes, or never true?

5. If you answered that the world mostly or sometimes works in a regular, predictable manner, do you think it is wise, in a practical sense, for scientists to assume this is always the case? Discuss the story of Hippocrates in relation to this question.

Rule #5: Uniformitarianism

Most people will agree that *most of the time* the world operates in a regular manner, according to some natural laws. Therefore, they have little problem with most science as it is now practiced. On the other hand, some people believe that this has not always been the case in the past. For example, some people believe that God created the world out of nothing in the not-too-distant past, and that other "miracles" occurred in the past. This poses a problem for the "historical sciences"—those that interpret the present state of things in terms of past events. For example, consider the popular TV series, *CSI*. In this show, crime scene investigators (forensic scientists) examine the details of a crime scene (blood spatter patterns, angles of bullet holes, objects that seem out of place, injuries evident on a dead body, etc.) and make up *stories* about how the present situation might have come about. In order to test their stories, they might shoot bullets into Jell-O, try to mimic the production of blood spatters, use trigonometry to determine from where a bullet might have come, and that sort of thing. The assumption implicit in all of these activities is that the crime scene reached its present state via processes that can be mimicked in the laboratory. They do not even consider the possibility that some supernatural entity might have been involved. Why? Because if they admitted such a possibility, all their normal methods for evaluating evidence would go out the window. Furthermore, when the case reaches the courtroom, even juries packed with deeply religious people tend not to listen to pleas by defense attorneys that supernatural entities adjusted crime scenes to make the defendants look guilty. This brings us to our next rule.

> *Rule #5. Any scientific explanation involving events in the past must square with the principle of "Uniformitarianism"—the assumption that past events can be explained in terms of the "natural laws" that apply today.*

How do we explain the presence of certain mountains that have a definite cone shape, and are otherwise similar (in rock type, etc.) to active volcanoes? The active volcanoes we know today spew out ash and lava, building on top of themselves to make a cone shape. Is it not reasonable to suggest that perhaps our mysterious cone-shaped mountains are extinct volcanoes? Consider fossils. They look like the remains of living things. Is it not reasonable to suppose that they were once living things that were covered and preserved in sediment, just as dead organisms can be covered and preserved in sediment nowadays? The idea here is *not* that everything has always been the same in every respect, or that catastrophic, out-of-the-ordinary events never happen. For example, many scientists believe that an asteroid impact led to the extinction of the dinosaurs. Rather, the idea is that the same "laws of nature" have always been in effect. For example, astronomers track the motions of asteroids whizzing around the solar system today, and one doesn't have to invoke the supernatural to suppose that a large asteroid might hit the Earth every once in a while

Once again, this is something we cannot know in any absolute sense, because we cannot travel back into the past to verify it. And even if we could travel back into the past, we certainly could not verify that the laws of nature have always operated in the same way at every moment, and in every location, in the past. Furthermore, we may well discover new "laws of nature" in the future that we have never noticed before, or discover that some of the laws familiar to us have exceptions.

We already mentioned that there could be supernatural agents who change how nature operates from time to time, and in fact, many people (including some scientists) believe that this has happened on occasion. Why would scientists, even those who do not believe it, make the assumption of Uniformitarianism, if it can never really be verified? This question can be answered by asking what would happen if scientists assumed the opposite, i.e., that for whatever reason, the laws of nature do not always operate in the same way. In that case, how could we explain any past events? Scientists draw inferences from *regularities* we observe in nature. Therefore, if we were to assume that these regularities did not operate in the same way in the past, science would have to be shut down, at least with respect to explanations involving past events. Again, scientists make this assumption as part of the cost of doing business, rather than because we are sure it is always true. Even if it is only true *most* of the time, such an assumption is probably worthwhile.

This kind of thinking is completely normal, both in science and everyday life. For example, when scientists perform calculations to predict the gravitational attraction between the Earth and other objects in space, they routinely assume that the Earth is spherical. They know perfectly well that the Earth isn't actually spherical—it is slightly squashed on two sides, and somewhat lumpy. However, the assumption that the Earth is spherical makes the math involved in the calculation so much more simple that the problem becomes easily solvable, and the answers we obtain are not very far off from those we would have gotten otherwise. As another example, consider the behavior of people who live in earthquake-prone areas. They get up and go to work, assuming all the while that no major earthquakes will occur that day, and yet they know in some corner of their minds that the "big one" might happen any time. They assume something that they know might not be true because their assumption will likely be true most of the time.

Questions for Thought/Discussion:

6. Do you think it is reasonable for scientists to assume Uniformitarianism when reconstructing the past? Why, or why not?

Rule #6: Simplicity

Another practical assumption is embodied in our next rule. Once again, it is the kind of assumption that must be made in order for science to keep operating.

Rule #6. Scientists assume that nature is simple enough for human minds to understand.

The assumption of Simplicity seems rather arrogant, doesn't it? After all, if humans are a small part of the natural order, how can our tiny brains ever comprehend the whole? Once again, you will not have to look far to find scientists who do not actually believe in this principle, or at least recognize it as unprovable (OKASHA, 2002, pp. 58-76; ORESKES et al., 1994), so why do they make this assumption, anyway? If they assumed that nature is *not* simple enough for the human mind to understand, scientists would have to give up on all their attempts to understand things. Therefore, even if the truth is that humans are only capable of understanding nature in a very limited way, it is immensely practical to make the assumption of Simplicity.

This rule could be considered a rather obvious point, and not directly related to the art of scientific storytelling. However, the assumption of Simplicity implies something very important about scientific stories—i.e., if nature is *understandable*, then we can come up with correct *explanations* for phenomena, and not just accurate *descriptions*. It is possible to make scientific stories that are more descriptive than explanatory, but the fact is that scientists value explanations more than descriptions. For example, Sir Isaac Newton created a simple, yet amazingly accurate mathematical equation to describe the force of gravitational attraction between objects, but he could not explain why such a force that acts at a distance should exist. Many of his fellow scientists were very uncomfortable with this, and called gravity an "occult" force (ROSENBERG, 2000, pp. 82-83). If scientists were content merely with description, rather than explanation, perhaps the idea of "action at a distance" wouldn't have caused such a stir. However, the search for an explanation for gravity was continued, and eventually Albert Einstein showed that gravitational attraction could be explained as an effect of the curvature of space-time around massive objects.

Now, if you are scratching your head and wondering what "the curvature of space-time" might mean, then it is an opportune time to point out another fact about the assumption of Simplicity. Namely, even though scientists assume nature is simple enough to understand, it does not follow that nature adheres to what we might call "common sense." The fact is that people don't usually form "common sense" judgments about things based on very careful observations, and when we force ourselves to observe carefully, it often turns out that reality doesn't conform to our expectations. For instance, the ancient Greek philosopher Aristotle explained that earthly objects fall downward because their natural place is on the earth, whereas fire goes upward because its natural place is in the heavens. This is a good "common sense" story that actually explains quite a bit of what people observe on an everyday basis. However, when more careful observations were made about the acceleration of falling bodies, the motion of the planets, etc., it soon became clear that Aristotle's physics could not do the job. The physics of Newton and Einstein were successive attempts to explain more and more careful observations that conflicted with a "common sense" view of the world (WOLPERT, 1992).

Therefore, even if nature is simple enough to understand, it does not follow that we can really understand it without an awful lot of hard work and creativity!

Questions for Thought/Discussion:

7. Do you believe nature is simple enough for humans to truly understand? Why, or why not? If not, do you think it is still reasonable for scientists to make this assumption in their work?

Rule #7: Harmony

Scientists generally want people to accept their stories and make use of them, but most people would hesitate to do so if they could see that different scientific explanations contradicted one another at every turn. Even if we can never be sure our explanations are correct, we don't want them to be a mass of confusion.

> *Rule #7. Scientific explanations should not contradict other, established scientific explanations, unless absolutely necessary.*

This last rule illustrates something truly grand and wonderful about science. That is, millions of scientists are continually working on creating their stories about various aspects of nature, but these should ideally not be a contradictory mass of confusion. Lord Kelvin, for example, connected his explanation of the sun to well-established principles like gravity and Joule's experiments involving motion and heat. The goal is to make one BIG story with a coherent plot from the millions of little stories scientists create.

Once again, when we look closely we find that scientific stories do not always fit perfectly together. However, it is by trying to resolve contradictions between different stories, and between scientific stories and observations, that scientists make progress.

Questions for Thought/Discussion:

8. Scientists generally do not think that they will ever reach the point where they have successfully explained everything. However, do you think there is merit in trying, anyway? Please explain your answer.

Conclusions

Clearly, science is not solely about discovering "facts" about the natural world, although scientists do spend a lot of time making observations and experiments. Rather, the real essence of science is *storytelling*—creatively making up stories to *explain* what we observe in the natural world. But how is science different than other kinds of attempts to understand the world? We have listed a few rules of thumb to help make this distinction, but in some cases these rules have clear exceptions. For example, scientific stories aren't always immediately testable, and therefore not always amenable to the constant winnowing process that scientists employ. They also don't always mesh perfectly with other established scientific explanations. However, scientists clearly place a much higher value on stories that make precise, testable predictions about the natural world, and mesh well with the other stories scientists tell. This *value system*, more than anything else, is what makes modern science so powerful. If scientists place more value on stories that predict new things, then the best scientific stories are the ones that are put at the most risk of failure. And when they do fail, scientists eventually try to find and fix the problems, leading to even more powerful stories. Similarly, the warning flags that go up when a scientific story doesn't mesh well with others can lead to more progress as scientists try to resolve the apparent contradictions. By constantly subjecting their stories to this kind of scrutiny, scientists try to make their stories *realistic*, even if we can never tell whether we have hit upon a completely true description of reality.

On the other hand, some of the rules explained here represent unprovable assumptions that scientists adopt in order to make the problems they tackle in some sense solvable. If there really were supernatural entities that sometimes alter the natural order, science would be blind to that fact. If nature were really too complex for the human brain to comprehend, science would ignore it. In some other fields of inquiry (e.g., religion or philosophy,) we can ask "why" things happen, or what "ought" to be done, but not in science. Science can help us control powerful processes like nuclear fission, but cannot tell us whether to use them for peaceful or warlike purposes. Indeed, scientists limit their stories to explaining only those observations that are reproducible, and this sometimes might exclude aspects of reality that are not easily transferable from one person to another. Therefore, science is a powerful, but limited, path to understanding.

When you see science for what it is—a powerful, yet limited and thoroughly human enterprise—it is our hope that you will be ready to make your own informed judgments about where scientific stories should fit in your own life, and in contemporary society.

Questions for Thought/Discussion:

9. If a scientific explanation turns out to be wrong, did the scientists who came up with it necessarily do something wrong in their work?

10. What role do you think science should play in your decision-making and belief systems? Explain your answers.

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Cast of Characters

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Introduction

Stories have to be consistent to be any good. Oh, we don't mind too much if characters in the story do some crazy-sounding things—science fiction and fantasy novels are very popular, after all—but if the characters do all kinds of *contradictory* things, the audience tends to get frustrated. Even if we don't really take the story that seriously (e.g., a fantasy novel,) we want to be able to at least suspend our disbelief for a while. This is why good authors spend time developing their characters (what kind of people are they?) and using the characters to move the plot of the story in a way that is consistent with that development. This kind of story seems to *ring true*.

Scientific stories are no different, except that we want this kind of story to not only *ring true*, but esasentially to *be true*. (Even if we realize that we have no way of recognizing when we have hit upon the Absolute Truth, we still want to get as close as possible.) In the essay "Science as Storytelling," we explained the principle of *harmony*, which states that "Scientific explanations should not contradict other, established scientific explanations, unless absolutely necessary." The point of this is that scientists really do *want* to create stories that are strictly true, and we figure that truth has to be consistent. Therefore, when we make up a scientific story to explain some phenomenon, we tend to use other scientific stories as a sort of *cast of characters*.

The principle of harmony actually plays out a little differently in different branches of science, depending on how *fundamental* they are. A fundamental science explains very basic concepts and processes. Of the natural sciences, physics is considered the most fundamental, with chemistry coming in second. (Of course, some branches of physics and chemistry are more fundamental than others.) In the most fundamental sciences, every attempt is made to harmonize theories, but it is likely that this will sometimes fail because we are trying to explain the basic structure and functions of the Universe in terms of human experience. Human experience, however, is very limited compared to the microscopically tiny or astronomically huge distances over which these basic processes operate. For example, physicists developed the theory of *quantum mechanics* to explain the behavior of molecules, atoms, and subatomic particles. It works quite well, but it has consequences that seem to contradict those of Einstein's theory of *relativity*, which was developed to explain the behavior of planets, stars, galaxies, and light traveling over huge distances. So far, nobody has come up with a universally accepted way to harmonize these theories.

Biology and the earth sciences, on the other hand, attempt to explain extremely complicated systems in terms of fundamental principles of physics and chemistry, and are considered to be *derivative*, rather than fundamental. In these sciences, we don't worry much about whether the physicists have finally unraveled the basic mysteries of the Universe by harmonizing quantum mechanics and relativity. Instead, we choose whatever fundamental theories are most appropriate for the phenomena we are faced with, and then try to explain the phenomena using these theories. For example, even if quantum mechanics doesn't mesh well with relativity, it still is very good for accurately predicting the behavior of atoms and molecules. So if biologists want to explain the behavior of atoms and molecules in biological systems, or earth scientists want to explain the behavior of atoms and molecules in rocks or water, they need to invoke principles that are in harmony with the basics of quantum mechanics.

In this unit, we will be exploring a few fundamental principles of physics and chemistry that will form a sort of *cast of characters* for the earth science stories you will be learning. If you understand these principles, that is, you will be able to clearly see how earth scientists came up with these stories. And in fact, you will find that you can actually use them yourself to basically explain lots of very complex phenomena related to geology, weather, etc. When you can do that, you will have come a long way in your preparation to teach science to elementary school children. You will be able to tell them *Earth Stories* that are satisfying and exciting, because their characters have been properly developed, and behave consistently.

Heat Transport

Many processes only happen at certain temperatures, or happen more quickly or slowly at different temperatures. Therefore, temperature will naturally play a big part in your scientific stories about earth processes.

But what do we mean by "temperature"? The temperature of an object is a measure of the kinetic energy of its atoms—"kinetic energy" is energy due to motion. When the object absorbs heat energy, its atoms move faster (i.e., gain kinetic energy,) raising the temperature. "Heat energy" is simply energy that can transfer between two objects, affecting the temperature of both. That is, the hotter object cools off as it transfers energy to the cooler object, which is heated up.

How does transport of heat energy occur? If you can explain that, you can explain quite a bit of what goes on here on the Earth.

Heat can be transported in three ways:

- Convection
- Conduction
- Radiation

Definitions and Simple Examples:

- **Convection:** Convection is a type of heat transfer that occurs when atoms capable of transferring heat energy are physically moved around. Then those atoms can transfer their heat energy to other atoms in their new environment by conduction or radiation.
  - E.g., a window fan blows air molecules into a room, so that the heat energy stored in those molecules is moved with them.
  - **Convection current:** A special kind of convection occurs through "convection currents." When there is a heat source at the bottom of a fluid, the bottom region of the fluid heats up and expands, making it less dense than the cooler part above. This makes the heated part more buoyant, so it floats to the top, and the denser, cooler part sinks to the bottom. Now, the cooler part of the fluid is on the bottom, heating up, and the warmer part is on the top, cooling down. Eventually, the bottom region becomes warmer and less dense than the top part, and they switch places again.

- E.g., when water heats on a stove, the water at the bottom of the pot is heated first. Therefore, convection currents can be created that mix the water around. This is one reason that the temperature of the water in the pot will remain fairly uniform throughout.

- **Conduction:** Conduction occurs when atoms transfer heat energy by bumping into one another.
  - E.g., when an empty frying pan is heated on its bottom, its atoms start to move faster, and bump into their neighboring atoms more frequently. When these collisions occur, heat energy is transferred. Therefore, the heat energy propagates along the whole length of the pan, and you can get burned just as easily by touching the top of the pan as by touching the bottom.

- **Radiation:** Atoms can actually emit energy in the form of electromagnetic waves. Other atoms can then absorb the energy when the emitted waves hit them. Electromagnetic waves can even travel through a vacuum.
  - E.g., when you stand next to a campfire, you don't have to touch the flames to feel the heat. The fire emits electromagnetic waves that are absorbed by the atoms in your skin.
  - E.g., the atoms of the Sun emit electromagnetic waves that travel through the vacuum in space and our atmosphere. When you stand in the sunlight, the atoms in your skin absorb the radiation. That's why it always feels cooler in the shade!

Complex Examples:

Life is rarely as simple as we would like it to be, and so it turns out that it is very difficult to find everyday examples where only one kind of heat transfer occurs. Even in the simple examples cited above, there is often more going on than we mentioned. Therefore, here we introduce a few examples that clearly involve more than one type of heat transfer.

- **Convection & Conduction:** When you put macaroni in hot water, why do the noodles cook, and why do they rise and fall in the water?
  - As water in a pot is heated, the atoms collide more frequently with the noodles, and heat energy is transferred by conduction. Meanwhile, convection currents also develop within the water, and the noodles swirl around with them.
- **Radiation & Conduction:** How does a pizza cook inside an oven?
  - A pizza is placed on a pizza pan, which is placed directly on the metal rack in the oven. The heating elements emit radiation, which is absorbed by both the top of the pizza and the metal pan and rack.
  - Since the metal rack, metal pan, and the pizza are in contact, heat is also transferred to the pizza by conduction.
- **Radiation, Convection & Conduction:** Remember the campfire example we cited earlier? Well, there is more to the heat you feel from a campfire than just radiation. In fact, you get a triple-whammy.

- The fire emits electromagnetic radiation, which travels through space and is absorbed by your skin, heating it.
- Meanwhile, air molecules around the fire have also absorbed some radiation, heating them up. Since the fire is on the ground, it can cause convection currents in the air. (Just watch the smoke swirling around above the fire and you can see their effects.) The convection currents can swirl the heated air molecules over in your vicinity.
- Finally, the hot air molecules that swirled over where you are sitting collide with your skin, and transfer heat energy by conduction.

Gravity, Buoyancy, and Density

In Earth systems, many different objects and substances are in contact with one another. What happens when they meet? Will they mix together? Will one end up on top of the other? The answers to these questions depend on the *forces* that act on the substances. In this section we will discuss forces due to *gravity* and *buoyancy*, and their relationship to the *density* of the substances they act upon.

Definitions and Simple Examples:

- **Density:** Density (ρ) is a measure of how much mass (m) is packed in a given volume (V).
  - $\rho = m/V$
  - I.e., if mass is how much 'stuff' there is in an object, density is a measure of how tightly that 'stuff' is packed together.
  - E.g., two blocks of the same size—one made of Styrofoam and the other of steel—would have different masses, and hence different densities.
- **Gravity:** Gravity is an attractive force that acts between all objects that have mass. The strength of the gravitational force (F_g) between two objects is proportional to the masses (m_1 and m_2) of the two objects, and inversely proportional to the square of the distance between the two (d^2).
  - $F_g \propto \frac{m_1 m_2}{d^2}$
  - This means that bigger objects will attract each other more strongly. For a clear explanation of why gravitational force can be predicted by an *inverse square law*, look up the following URL on the Internet.
    - http://hyperphysics.phy-astr.gsu.edu/hbase/forces/isq.html
  - E.g., since gravitational force drops off rapidly with distance, objects tend to experience the most gravitational attraction to the closest large object. In our case, the Earth is the closest large object to us, so we feel the most gravitational attraction toward it.
    - MISCONCEPTION!!! *Many people think that the Earth attracts us via gravity, but they do not think that we attract the Earth. This is*

false. Remember that Newton's 3rd Law of motion says that all forces occur in pairs, and for every force, there is an equal force exerted in the opposite direction. So if the Earth exerts a force due to gravity on us, then we must exert an equal force attracting the Earth toward us. So why does it seem like we fall toward the Earth, but the Earth doesn't fall toward us? To answer this question, try exerting a force on a small rock by poking it. It should move. Then try poking a large boulder with the same amount of force. Maybe it did move, but the motion was probably imperceptibly small. The point is that the same amount of force moves smaller (i.e., less massive) objects more than bigger objects. So gravitational forces between you and the Earth do move the Earth—just not very much.

- E.g., if the Moon is attracted to the Earth via gravity, why doesn't it collide with Earth? The moon is just moving too fast! If we could "turn off" gravity between the Earth and Moon, the Moon would shoot off into space in a straight line, in the direction it was traveling when the switch was thrown. The force of gravity between the Earth and Moon acts like a "string" that keeps the Moon orbiting around the Earth, rather than shooting off into space. If the Moon were traveling more slowly, it would spiral down and collide with the Earth.
  - E.g., if you want a demonstration, tie an object to a string and swing it around your head. If you don't swing it fast enough, the object falls. If you let go mid-swing, the object flies off in a straight line.
- Gravitational forces are directed toward the "center of mass" of an object—which is sort of the average position of all the object's mass. That is why objects around here fall toward the center of the Earth. We can usually calculate gravitational forces on an object pretty accurately by assuming that all of its mass is concentrated at the center of mass.
- Since gravitational forces drop off so rapidly with distance, the density of the objects involved can be very important in determining how strong those forces can be.
  - E.g., we are standing about 6371 km from the center of the Earth. What would happen if we were to squash all the mass of the Earth into half the volume? Then if we stood at the surface of the Earth, we would be about 5057 km from its center. This is approximately 79% of the present distance, and since gravity drops off as the inverse square of distance, and $\frac{1}{0.79^2} \approx 1.6$, while $\frac{1}{1^2} = 1$, you would weigh 60% more standing on the surface of our condensed Earth. In other words, if you weigh 100 lbs, you would gain 60 lbs just by being able to come 20% closer to the center of the Earth!

- **Buoyancy:** The *buoyant force* is an upward force on an object produced by the surrounding fluid, caused by the difference between the pressure at the top of the object, which pushes it downward, and the pressure at the bottom, which pushes it upward. That is, fluid pressure increases toward the bottom, because the fluid toward the top presses down on the fluid at the bottom due to gravity. Therefore, if you place an object in the fluid, the pressure exerted on its bottom is greater than that exerted on its top, and the object experiences a net upward force.

- An object immersed in a fluid is subject to both the upward buoyant force and the downward force of gravity. The result is that the object will float or sink, depending on which force is larger.
- It turns out that the buoyant force is governed by Archimedes' Principle, which says that the buoyant force on an object is equal to the weight of the fluid the object displaces.
- The result is that objects more dense than the surrounding fluid will sink, while objects less dense will float. Also, objects that float will sink until the weight of fluid they displace is equal to the weight of the object.
- E.g., a rock sinks in water, but a piece of wood floats, because the rock is more dense than water, while the wood is less dense. When wood floats, it doesn't lie completely on top of the water, but sinks down in a little.
- E.g., we can make a boat out of dense materials like steel by making the boat hollow. That is, a hollow object has to displace a greater mass of fluid, so if there is enough hollow space, the object can displace its weight in fluid before it sinks all the way.
- E.g., Hot air balloons float because the hot air inside them is less dense than the air outside, allowing the balloon to become buoyant.

Physical vs. Chemical Changes

Elementary school teachers are expected to help students understand the different changes they see around them, and the curricula for this age group usually divide these changes into two categories: physical and chemical.

Definitions and Simple Examples

- **Physical Change:** An object that undergoes a *physical change* is either deformed or changes phase (i.e., goes between solid, liquid, and gas phases,) but the identity of the substance does not change. In other words, the *object* changes, but the *substance* does not.
    - E.g., if you break a rock, bend a wire, chop a carrot, or melt an ice cube, you have caused a physical change. There has been a change, but the substances are still the same.
- **Chemical Change:** A chemical change occurs when atoms and molecules react to form one or more new substances.
    - E.g., if you mix flour, water, eggs, sugar, oil, etc., and then bake the mixture to make a cake, the heat causes chemical changes to occur so that the cake is now something different than the original ingredient mixture.

  - E.g., if you mix baking soda (sodium bicarbonate) and water, carbon dioxide gas bubbles out. A chemical reaction has occurred between the baking soda and water to make a new substance (carbon dioxide gas.)
- MISCONCEPTION!!! *Many elementary school science textbooks teach that you can distinguish physical and chemical changes by noting that physical changes are reversible, while chemical changes are not. This is false!* The fact is that most familiar chemical changes are usually *harder* to reverse than most familiar physical changes, but both physical and chemical changes can be reversible or irreversible.
  - E.g., if you bend a wire (a physical change,) you can just bend it back. But if you burn a piece of toast (a chemical change,) it would be pretty hard to turn the ash back into bread.
  - E.g., smashing a rock with a hammer is obviously a physical change—little bits of rock are still the same substance as the larger piece. But that it would be pretty hard to reverse that change! (Using glue is cheating.)
  - E.g., an iron pipe exposed to water can turn to rust (iron oxide), which is a chemical change. It would take a lot of energy, but if you were to heat the rust up in a blast furnace, you could drive off the oxygen and make iron again!

Phase Changes

A phase change occurs when a substance shifts between the three states of matter: solid, liquid and/or gas. Since a phase changes do not change the identity of a substance (e.g., water vapor, ice, and liquid water are still just water,) they are considered to be a type of physical, rather than chemical, change.

Phases

You probably already have a fairly clear idea about the difference between a solid, liquid, and gas, but just to make sure your conception is clear enough for the elementary school students that you will be teaching, we will quickly explain it again. The difference between phases of the same substance is simply the way the atoms or molecules move relative to one another, which has consequences for its larger-scale behavior.

- **Solids:** In a solid, the atoms generally vibrate around the same positions. The higher the temperature, the more they vibrate, but they still mostly stay connected together in the same way. Because of this, solids tend to hold their shapes unless deformed by some external force. (See "Deformation of Solids" below.)
- **Liquids:** As the temperature in a solid rises, the atoms and molecules vibrate more and more vigorously. Eventually, they are moving so much that they start pulling apart and moving about more freely. They are still bonded together, but the bonds break and re-form much more easily, so they can move around more. At this point, the substance is a liquid. Because of the way its molecules move, liquids tend to stay together, but not to hold their shapes. (E.g., when you pour a liquid into a cup, the liquid stays together at the bottom of the cup, but takes on the shape of that part of the cup.)

- **Gases:** As a liquid is heated, it molecules also move about more vigorously. Eventually, some of those molecules will have enough kinetic energy to break all their bonds and go flying off into space. These molecules are now in the gas phase. Gas molecules zip around all the space that is available to them, bouncing off each other, walls, floors, ceilings, etc. For this reason, gases exert *pressure* on the walls of whatever contains them. That is, gas molecules bouncing off walls naturally exert force on those walls. If the molecules move faster because the temperature is raised, then the force they exert is also increased. (E.g., a balloon will expand if you raise the temperature, or contract if you lower it.)

Phase Change Processes

You are probably also familiar with most phase change processes, like melting or boiling, but odds are that you are not familiar with some of the less common ones, like sublimation or deposition. Read on to see if you find out something new.

- **Melting:** Solid → Liquid
  - E.g., if you heat up iron enough, it will eventually melt to form a liquid.
- **Freezing:** Liquid → Solid
  - E.g., molten (liquid) iron, it will freeze to form the solid metal again. (Some people think of "freezing" as only referring to water.)
- **Boiling:** Liquid → Gas
  - E.g., everyone knows that water boils to make water vapor, or steam, but most people don't realize that what they normally call "steam" is really tiny, airborne drops of liquid water. When you boil water on a stove, the liquid water does turn to water vapor and flies off into the air. But the air around the kitchen is much cooler than it was inside the hot pan, so the water vapor condenses back to the liquid phase. This is the cloudy looking stuff that you see pouring off the water—water vapor is actually a colorless gas, so you can't see it.
- **Condensation:** Gas → Liquid
  - E.g., under the right conditions (really, really low temperature,) nitrogen gas can be condensed to form liquid nitrogen.
- **Sublimation:** Solid → Gas
  - E.g., dry ice (frozen carbon dioxide) can turn directly into gaseous carbon dioxide, without melting.
  - E.g., it is less well known that other substances can do the same thing. For instance, have you ever noticed that the ice cubes in your freezer shrink if you leave them in there for a long time? This is because the ice sublimes over time if the air isn't too humid.
- **Deposition:** Gas → Solid

- E.g., you can heat up a metal plate with a laser and turn it into a gas, which then deposits as a solid coating on whatever surfaces are around. Had you ever heard of a metal gas before this?
- E.g., when you freeze water, does it generally turn out looking like a snowflake? How do these tiny, delicate crystals form so perfectly? The truth is that water vapor molecules deposit themselves on a tiny surface without going through a liquid phase. This allows the molecules to position themselves "just so," to make nice crystals.

Composition, Temperature, and Pressure Control of Phase Changes

Phase changes are controlled by three main factors: composition, temperature, and pressure.

- **Composition:** Different substances are bonded together with different strengths, so naturally it is harder to change phases for some than others.
  - E.g., it takes a lot more heat energy to melt iron than ice.
  - E.g., adding salt to ice on the road causes its melting temperature to rise, so that it melts more easily.
- **Temperature:** This one is obvious. You have to change the temperature to affect a phase change, because changing the temperature means changing the kinetic energy of the molecules.
- **Pressure:** The gas, liquid, and solid phases of a material typically have different densities. More pressure applied to the material, therefore, makes it more likely to adopt the more dense phase.
  - E.g., most materials, like iron, are denser in the solid than the liquid phase. If more pressure is applied, the melting temperature of these materials is raised. That is, it is harder to melt at higher pressures because it wants to stay in the more dense phase.
  - E.g., water is a strange material, in that its solid phase (ice) is *less* dense than its liquid phase. (That's why ice floats in water.) When more pressure is applied to ice, its melting temperature is actually lowered. That is, it is easier to melt at higher pressures because it wants to assume the more dense, liquid phase. This is actually why ice skates work. All of the skater's weight pushes down on a very small area, creating a high pressure. The ice underneath melts, even though the temperature has stayed the same, and the skate can glide easily across the wet, slick surface. If ice did not behave this way, the skates would probably stick to the ice surface. (Note: While the general principle is true, some scientists dispute the idea that ice skates could put enough pressure on the ice to significantly lower its melting temperature. However, I think they are total kill-joys.)

Chemical Reactions—Composition, Temperature, and Pressure Control

The rate and extent of chemical reactions also depends on composition, temperature, and pressure—and for the same reasons as phase changes. Different chemicals have different tendencies to bond with one another. Higher temperatures favor whichever side of the reaction involves more molecular motion. Higher pressures favor denser materials.

Deformation of Solids

Many physical processes on the Earth involve changing the shape of solid materials in response to applied forces, but there are actually three different ways this can happen.

Definitions and Simple Examples

- **Elastic Deformation:** When forces are applied to a solid, it may start to bend. As it bends, it builds up *strain energy*. If the forces are released, the solid will release its strain energy and return to its original shape.
    - E.g., you can apply forces to a rubber band and stretch it out, but this builds up strain energy in the rubber so that when you let go of the rubber band it returns to its original shape (after it hits whomever you were aiming at.)
- **Brittle Deformation:** Solids can only build up so much strain energy before they break. Deformation by breaking is called brittle deformation.
    - E.g., if you stretch a rubber band too much, it can release its strain energy by breaking and snapping your hand, rather than hitting your intended target.
    - E.g., if you bend a stick it builds up strain energy, and will snap back to its original shape (elastic deformation) if you let go. But if you keep bending it, eventually it will snap in two (brittle deformation.) You can then feel the strain energy being released via painful vibrations in your arms.
- **Plastic Deformation:** When stress is applied to some solids, they undergo *plastic* deformation, meaning that they change shape while the stress is being applied, and then stop changing shape when it stops. Plastic deformation is more likely at higher temperatures and pressures.
    - E.g., modeling clay is a solid, but if you push on it, it will deform. When you release the pressure, it keeps its shape.
    - E.g., when you head up a glass tube in a flame, it can become somewhat flexible even before it melts. Glass blowers manipulate heated, but solid, glass to make intricate structures, whereas melted glass just turns into a glowing blob. Remember that higher temperature just means that the molecules are moving more vigorously. This makes it more likely for bonds to break and re-form, which is what needs to happen in plastic deformation.
    - E.g., remember how higher pressure favors the presence of more dense materials? Now think of what happens when a solid undergoes brittle deformation—it cracks, creating new open space. On the other hand, plastic

deformation does not create new open space, so higher pressure favors plastic deformation.

Period 1: Course Introduction

Learning Outcomes

After attending class and completing your reading assignment, you should be able to answer questions related to the following.

- Why did Dr. Bickmore choose the theme "Earth Stories" for the course?
- Why is this class relevant to your life?
- What other classes are you required to take so that you can learn the earth science content you will need to teach elementary grades?
- What are the learning outcomes for the course?
- What is the general procedure we will follow in class?
- What is the general procedure you will follow between classes?
- What percentage of your final grade are the tests worth?
- How can you get extra credit in the class?
- What does Dr. Bickmore consider a sufficient excuse for missing class, so he will allow make-up work?
- When are your online quizzes due?

Reading Assignment

- Read the introductory essay before the syllabus in the course packet.
- Read the syllabus.

Online Quiz!

- Complete the quiz before the next class period.

Period 2: The Nature of Science

Learning Outcomes

After attending class and completing the assigned reading, you should be able to answer questions about the nature of science related to the following.

- In what way are scientific hypotheses and theories really a kind of *story*?
- What is the main difference between scientific and other types of stories that attempt to explain things about the world?
- What does it mean to say that scientific observations must be "reproducible"?
- What is a "hypothesis"?
- What is the difference between a "hypothesis" and a "theory"?
- How does the "Scientific Method" help us make more and more useful stories?
- Why can't scientific stories appeal to supernatural causes?
- Why do scientists use the principle of Uniformitarianism to explain past events?
- What does the assumption of simplicity mean?
- Is it possible for different scientific explanations to conflict with one another?
- How do scientists respond to conflicting stories?

Reading Assignment

- Read the "Science As Storytelling" essay in this packet.

Online Quiz!

- Complete the quiz before the next class period.

Period 3: Cast of Characters

Learning Outcomes

After attending class and completing the assigned reading, you should be able to answer questions related to the following.

- What does it mean when I say that some branches of science are more *fundamental* than others?
- What are geologists essentially doing when they make up their scientific stories?
- Name and define the different methods of heat transport.
- Be able to recognize which method(s) of heat transport is (are) involved in processes described to you.
- Define gravity, buoyancy, and density. Explain how these three things work together or affect one another.
- What misconceptions do people often have about gravity, density, and buoyancy?
- If you are given example objects, be able to predict whether they will sink or float in a given medium.
- Define *physical change* and *chemical change*. What is the difference?
- Given an example process, be able to recognize whether it primarily involves a physical or chemical change.
- Explain the different states (phases) of matter in terms of molecular motion and macroscopic properties.
- Name and define the different processes involved in phase changes.
- Explain how composition, temperature, and pressure affect phase changes. Make sure to mention the role of density.
- Explain how composition, temperature, and pressure affect chemical reactions.
- Name and define the different types of solid deformation processes.
- Given an example process, be able to recognize which solid deformation processes are involved.

Reading Assignment

- Read the "Cast of Characters" essay after the syllabus in this packet.

Online Quiz!

- Complete the quiz before the next class period.

Period 4: Earth History

Learning Outcomes

After attending class and completing the assigned reading, you should be able to answer questions related to the following.

- How do most scientists think that the Solar system first formed? Be able to explain it in terms of fundamental physical principles.
    - What kinds of observations support this story?
- From what kind of material do scientists think the Earth was formed, and when do they think this happened?
    - What kinds of observations support this story?
- How do scientists think the layered nature of the Earth came to be?
    - What are the different layers made of?
    - Why have these particular materials collected at particular levels in the Earth system?

Terms and Concepts to Know

Set 1
Earth science
Earth
geology
meteorology
biology
biosphere
hydrosphere
atmosphere
solid Earth
system

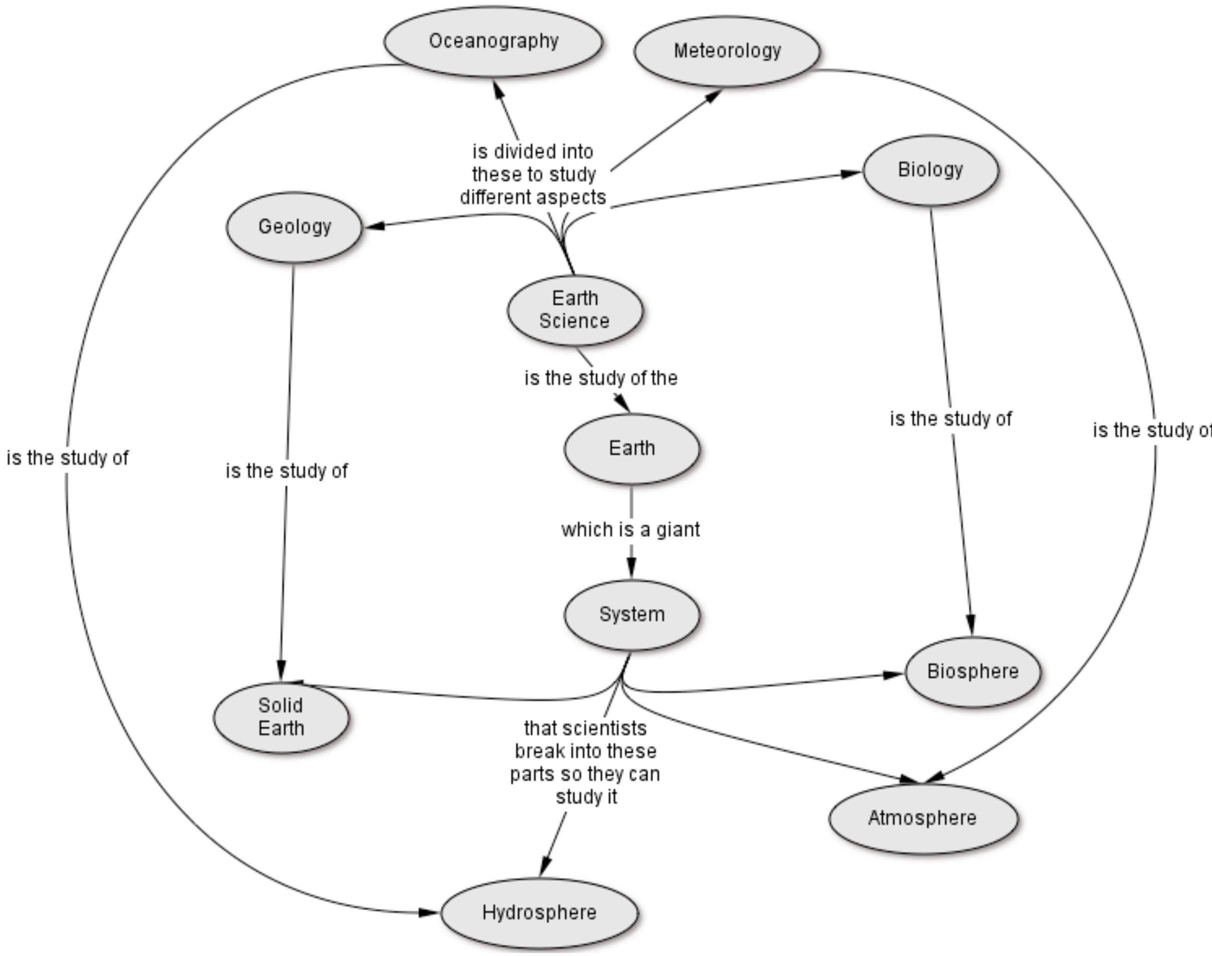
Set 2
inner core
outer core
mantle
asthenosphere
lithosphere
crust
rock
metal
liquid
solid
brittle
softened solid

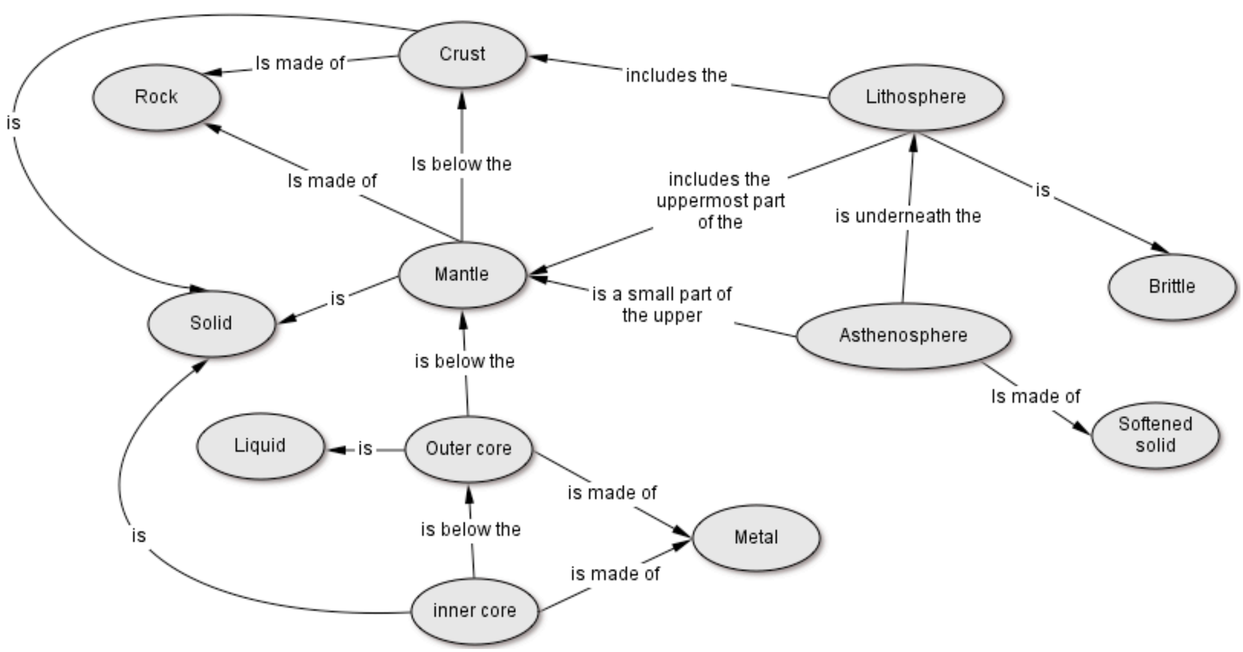
Reading Assignment

- Read the sections on "Formation of Planets" and "Meteoroids" from Ch. 15 of Lutgens and Tarbuck.
- Also read the "Introduction to Earth Science" chapter, up to (but not including) the section on "The Nature of Scientific Inquiry." (We already covered that better than your textbook.)

Online Quiz

- Complete the quiz before the next class period.


Oceanography
Meteorology
is divided into these to study different aspects
Biology
Geology
Earth Science
is the study of the
Earth
is the study of
is the study of
is the study of
is the study of
which is a giant
System
Solid Earth
Biosphere
that scientists break into these parts so they can study it
Atmosphere
Hydrosphere


Crust
Is made of
Rock
includes the
Lithosphere
is
Is below the
Is made of
includes the uppermost part of the
is
is underneath the
Brittle
Mantle
is
Solid
is a small part of the upper
Asthenosphere
is below the
Is made of
Softened solid
Liquid
is
Outer core
is made of
is
is below the
Metal
is made of
inner core

Period 5: Minerals

Learning Outcomes

After attending class and completing the assigned reading, you should be able to answer questions related to the following.

- What is a mineral?
  - Given examples, be able to tell whether they are minerals or not.
- What is an atom, and why do minerals in atoms bond together?
  - What types of bonds are usually the strongest?
- Why do minerals grow with peculiar, geometric shapes?
  - In what circumstances might they take other shapes?
- What are the eight most common elements in the continental crust?
- Which group of minerals is the most common?
  - Why is it the most common?
- If more silica is present in a system, then what changes about the nature of the silicate minerals present?

Terms to Know

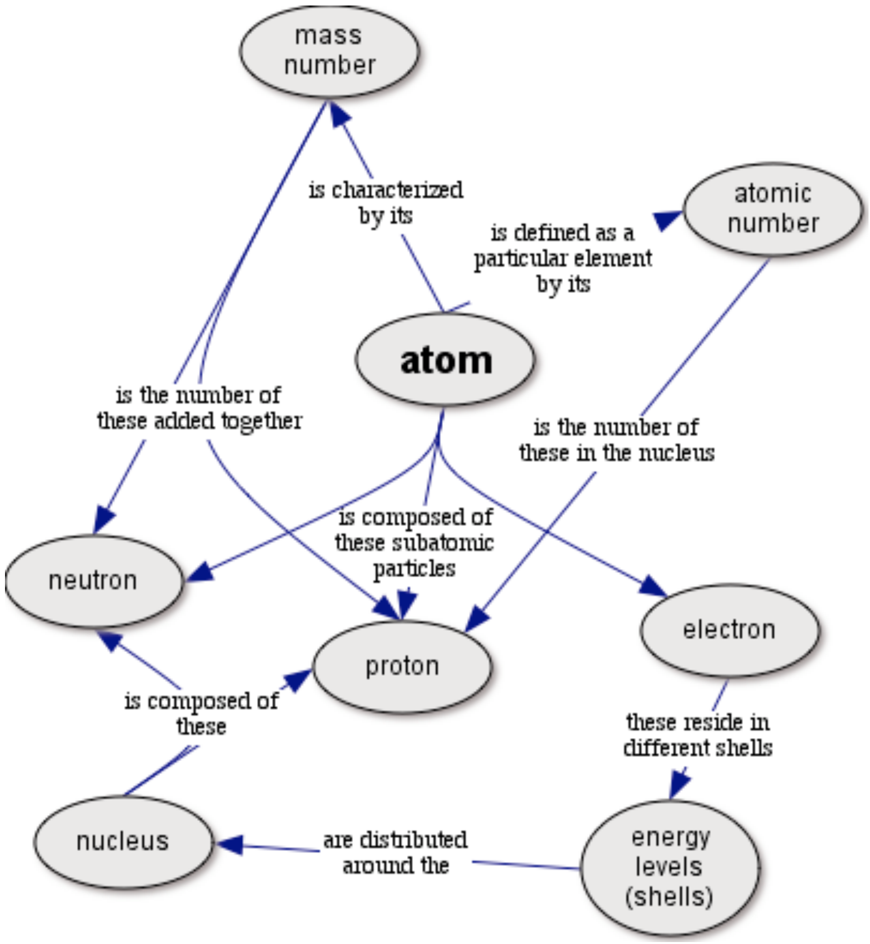
Set 1	*Set 2*	*Set 3*
atom	atom	mineral
electron	proton	rock
neutron	neutron	silicates
proton	electron	crystalline
nucleus	element	naturally occurring
energy levels (shells)	ion	solid
atomic number	isotope	well-defined chemistry
mass number		specific crystal structure
		periodic arrangement of atoms

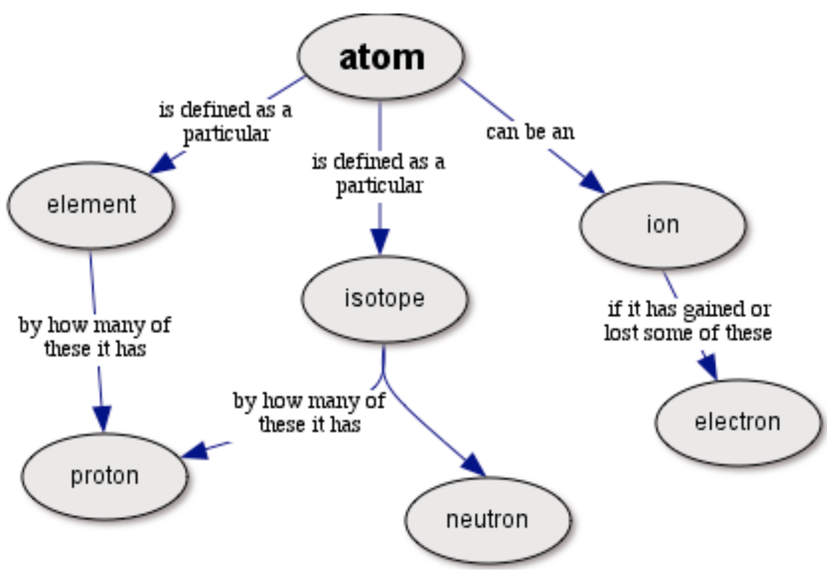
Reading Assignment

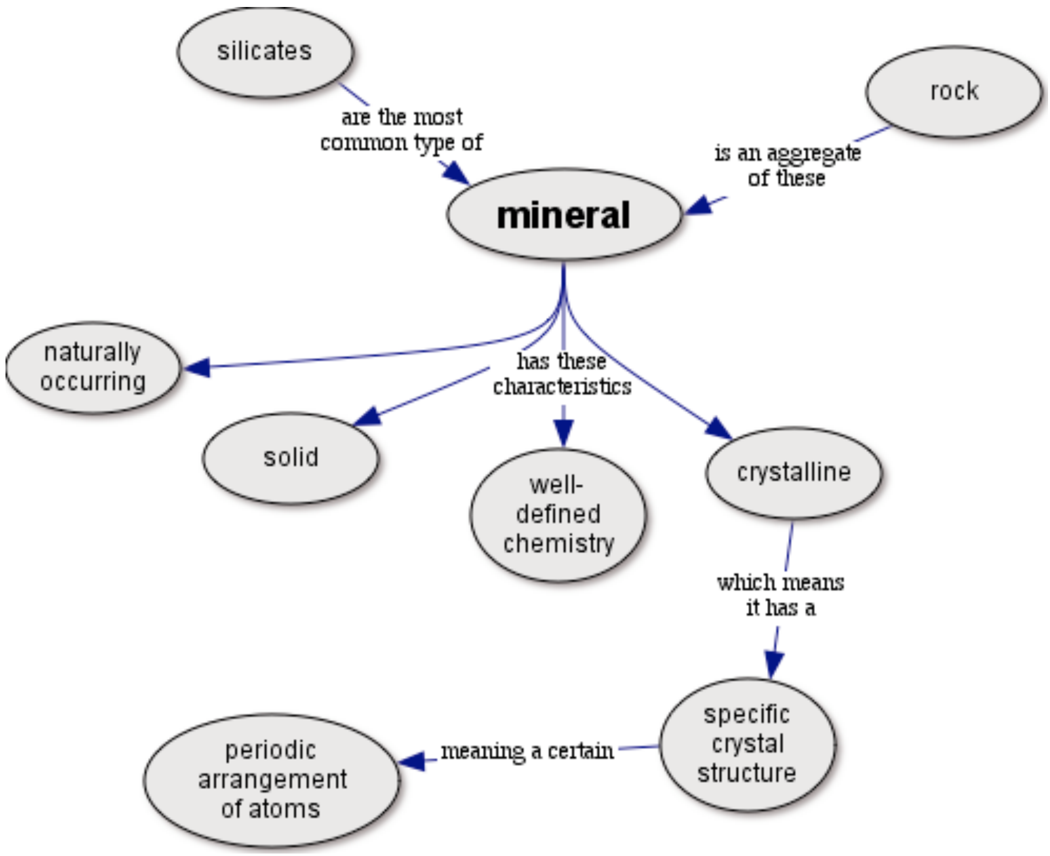
- Read Ch. 1 of Lutgens and Tarbuck.

Online Quiz!

- Complete the quiz before the next class period.


mass number
is characterized by its
atomic number
is defined as a particular element by its
atom
is the number of these added together
is the number of these in the nucleus
is composed of these subatomic particles
neutron
proton
electron
is composed of these
these reside in different shells
nucleus
are distributed around the
energy levels (shells)


atom
is defined as a particular
is defined as a particular
can be an
element
isotope
ion
by how many of these it has
by how many of these it has
if it has gained or lost some of these
proton
neutron
electron


silicates
are the most common type of
rock
is an aggregate of these
mineral
naturally occurring
has these characteristics
solid
well-defined chemistry
crystalline
which means it has a
specific crystal structure
meaning a certain
periodic arrangement of atoms

Periods 6-8: Rocks

Learning Outcomes

After attending class and completing the assigned reading, you should be able to answer questions related to the following.

- Explain the rock cycle IN DETAIL
- How are the different rock types classified, and why scientists did choose each classification scheme?
- Be able to explain and differentiate between the different types of metamorphism.
- You should know that, for example, rhyolite is granitic (felsic) in composition, which means that the magma was probably at a fairly low temperature (for a magma) and probably originated somewhere higher in the crust than other magmas. It is also fine-grained (aphanitic) in texture, which means that it is of volcanic origin. Be able to make the same connections for all the rocks listed in Figure 2.8 on p. 44.
- Explain the point of Bowen's Reaction Series, shown in Figure 2.9 on p. 41.
- Explain the processes rocks undergo to form different types of sedimentary rocks.
- How does physical weathering enhance chemical weathering?
- What are the main agents of metamorphism?
- What changes happen to a rock during metamorphism?
- What do mineral content and foliation tell you about the origin of a metamorphic rock?
- Be able to give a basic story about the origin of the following metamorphic and sedimentary rocks: slate, phyllite, schist, gneiss, quartzite, marble, shale (mudstone), siltstone, sandstone, conglomerate, breccia, limestone, evaporites (e.g., rock salt and rock gypsum).

Terms and Concepts to Know

Set 1
Igneous rocks
temperature of formation
texture (grain size)
course grained (phaneritic)
where it formed
porphyritic
glassy
silica content
granitic (felsic)
andesitic (intermediate)
basaltic (mafic)
ultramafic
fine-grained (aphanitic)

Set 2
sedimentary rocks
lithification
weathering
erosion
chemical weathering
sedimentation
dissolved minerals
chemically altered minerals
mechanical weathering
chemical sedimentary rocks
detrital sedimentary rocks
detritus
physical sedimentation
chemical sedimentation

Set 3
grain size
salts like halite
chemical sedimentary rocks
calcite
mudstone/shale
mineral content
dolomite
detrital sedimentary rocks
siltstone
limestone
sandstone
dolostone
conglomerate/breccia
evaporites

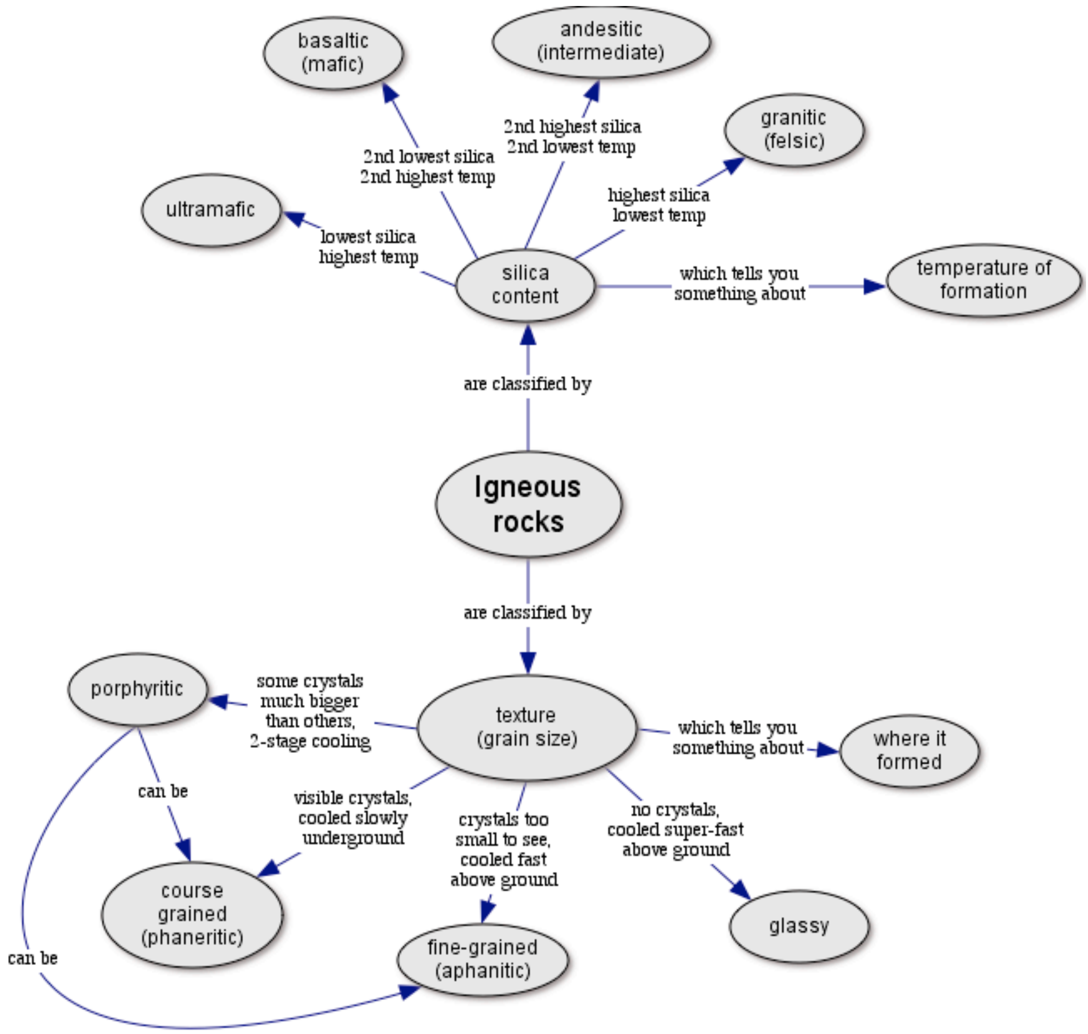
Set 4
metamorphic rocks
foliated/non-foliated
conditions of metamorphism
minerals present
appearence
temperature
directed pressure

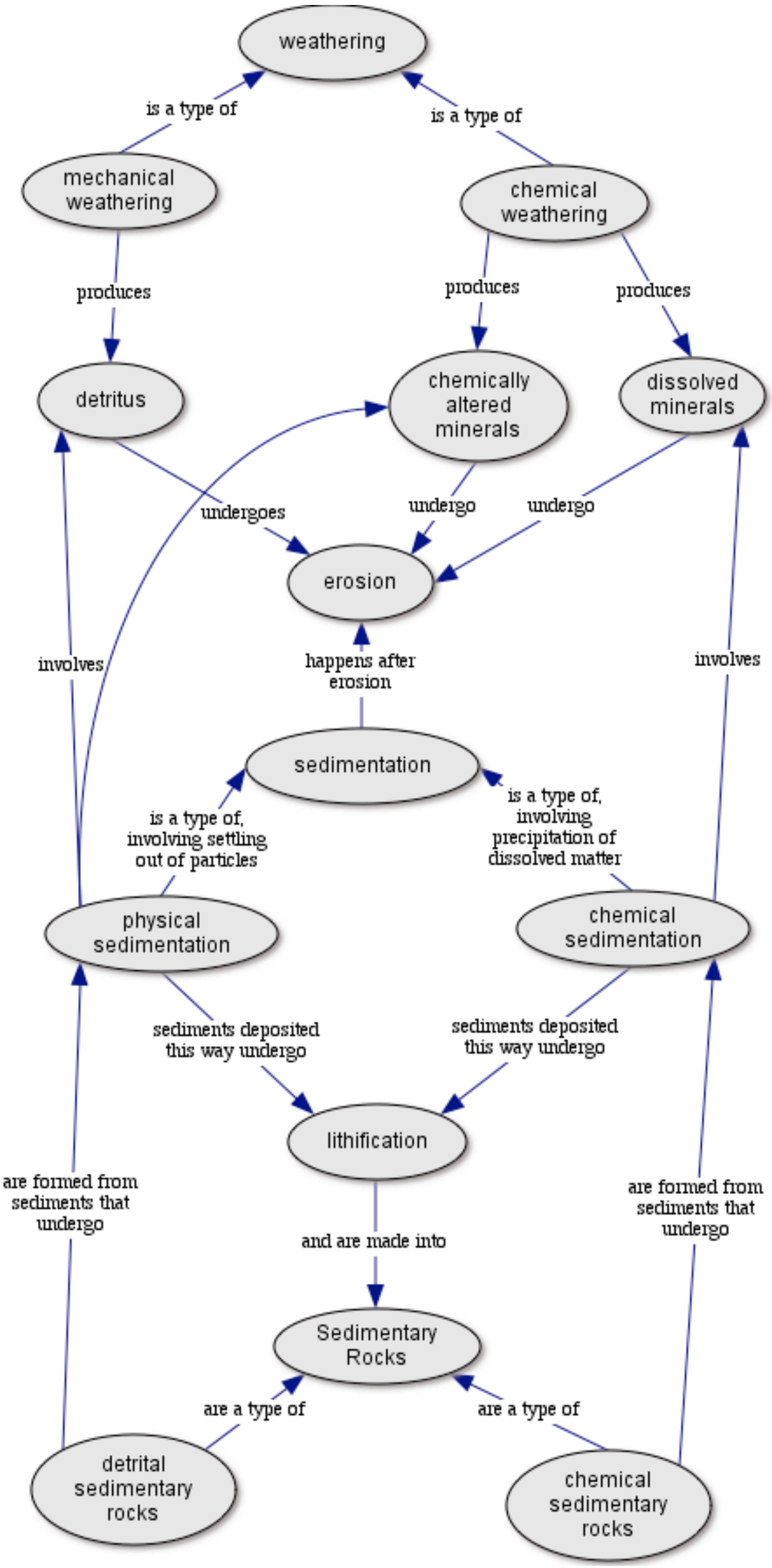
Reading Assignment

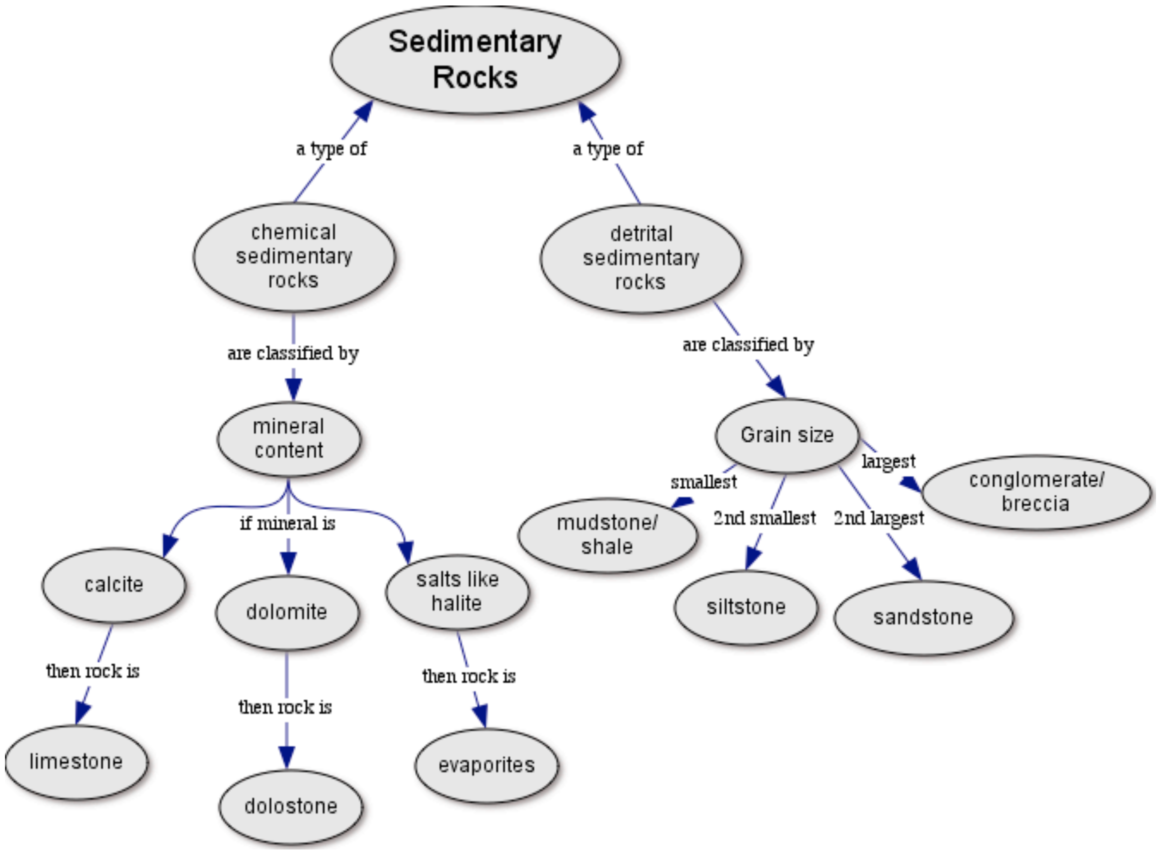
- Read Ch. 2 of Lutgens and Tarbuck.

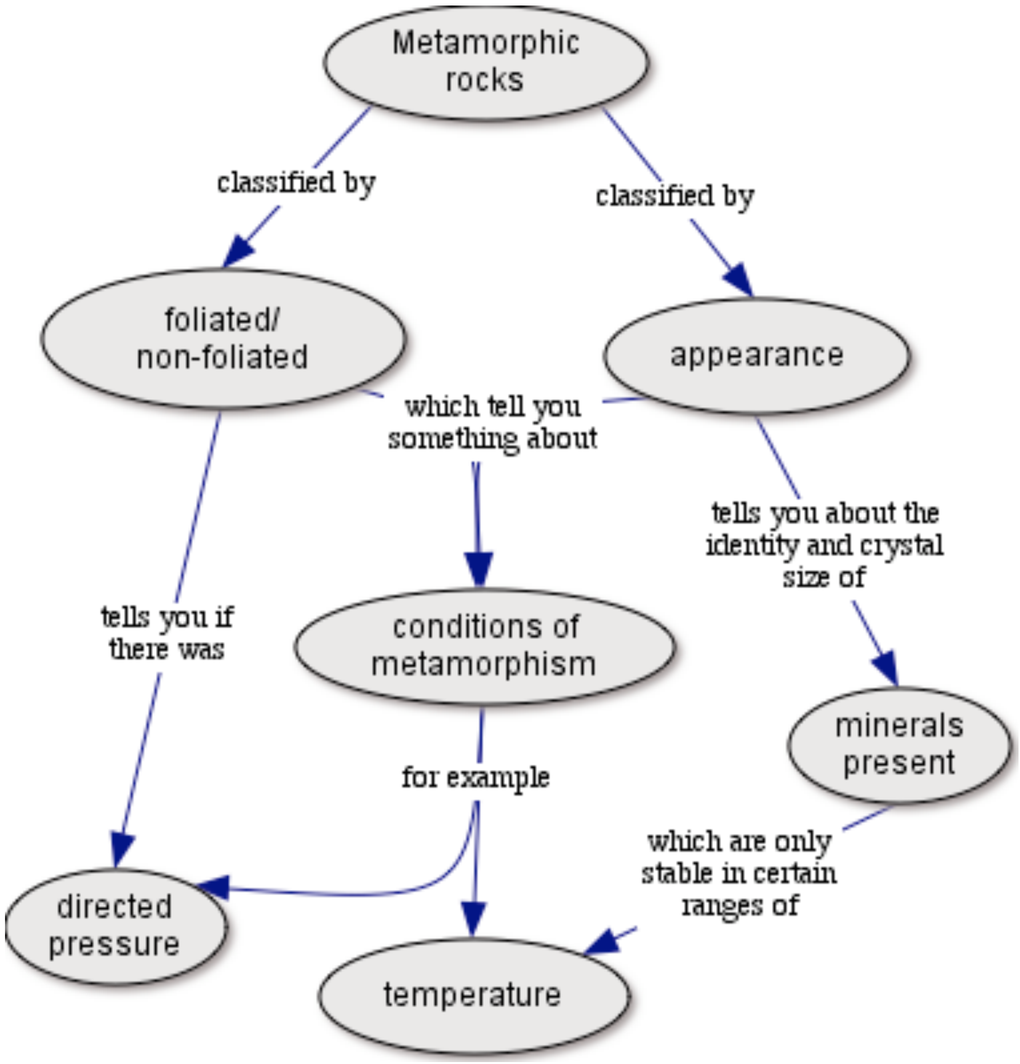
Online Quiz!

- There will be an online quiz on Blackboard due 30 min. before the next class.




weathering
is a type of
is a type of
mechanical weathering
chemical weathering
produces
produces
produces
detritus
chemically altered minerals
dissolved minerals
undergoes
undergo
undergo
erosion
involves
happens after erosion
involves
sedimentation
is a type of, involving settling out of particles
is a type of, involving precipitation of dissolved matter
physical sedimentation
chemical sedimentation
sediments deposited this way undergo
sediments deposited this way undergo
lithification
are formed from sediments that undergo
and are made into
are formed from sediments that undergo
Sedimentary Rocks
are a type of
are a type of
detrital sedimentary rocks
chemical sedimentary rocks


Sedimentary Rocks
a type of
a type of
chemical sedimentary rocks
detrital sedimentary rocks
are classified by
are classified by
mineral content
Grain size
if mineral is
calcite
dolomite
salts like halite
then rock is
then rock is
then rock is
limestone
dolostone
evaporites
smallest
2nd smallest
2nd largest
largest
mudstone/ shale
siltstone
sandstone
conglomerate/ breccia


Metamorphic rocks
classified by
classified by
foliated/ non-foliated
appearance
which tell you something about
tells you about the identity and crystal size of
tells you if there was
conditions of metamorphism
minerals present
for example
which are only stable in certain ranges of
directed pressure
temperature

Periods 9-11: Geologic Time

Learning Outcomes

After attending class and completing the assigned reading, you should be able to answer questions related to the following.

- What techniques do geologists use to figure out how old geologic features are? What assumptions do they have to make?
- How old do scientists say the Earth is? How did they come up with that particular number?
- If I tell you the ratio of parent to daughter isotopes in a mineral and the half-life of the decay reaction, you should be able to tell me how old the mineral is.
- What are the major claims of evolutionary theory?
- What kinds of geologic evidences support evolutionary theory?
- Know the geologic timescale, as given in lecture.

Terms and Concepts to Know

Set 1
Dating techniques
Relative dating
Daughter isotope
Inclusions
Radiometric dating
Uniformitarianism
Fossil succession
Original Horizontality
Numerical dating
Superposition
Parent isotope
Cross-cutting relationships
Original horizontality

Set 2
Widely separated rocks
Rocks in contact
Radiometric dating
Fossil succession
Relative dating
Correlation

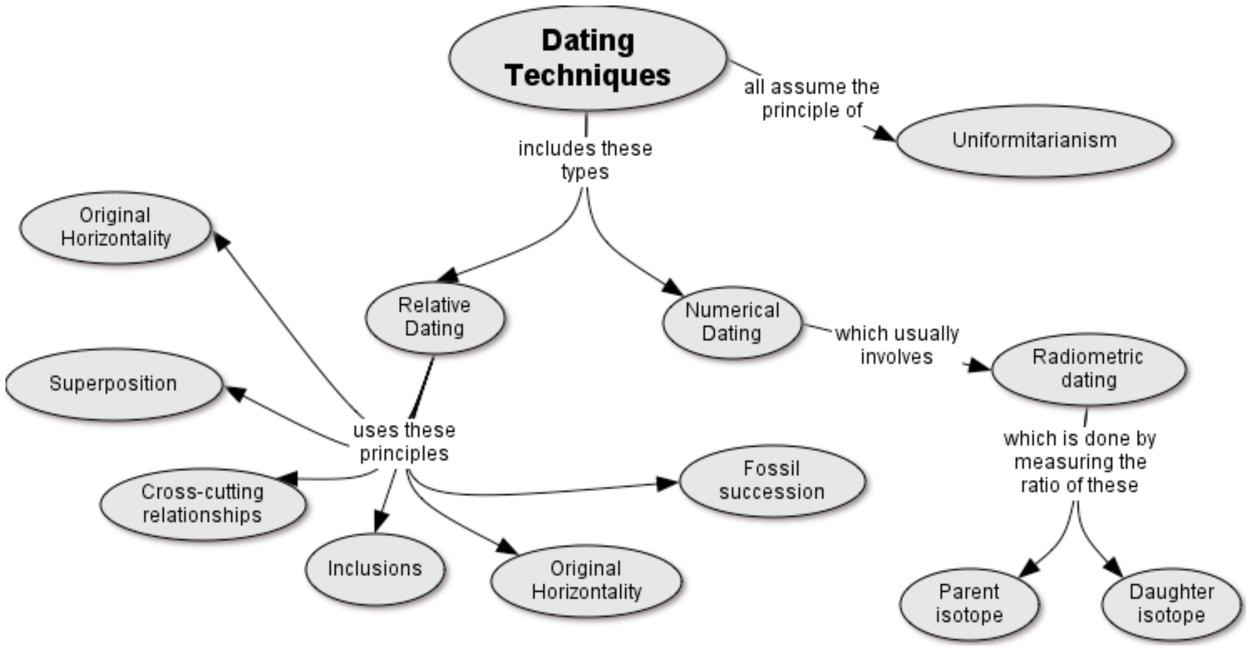
Set 3
Evolutionary Theory
Long Earth history
Species descend from other species
Common descent of all species
Natural selection
Relative and radiometric dating methods agree
Fossil record documents gradual changes
Transitional forms
Archaeopteryx
Geographic distribution of species explained by geologic history
Simpler life-forms preceded more complex

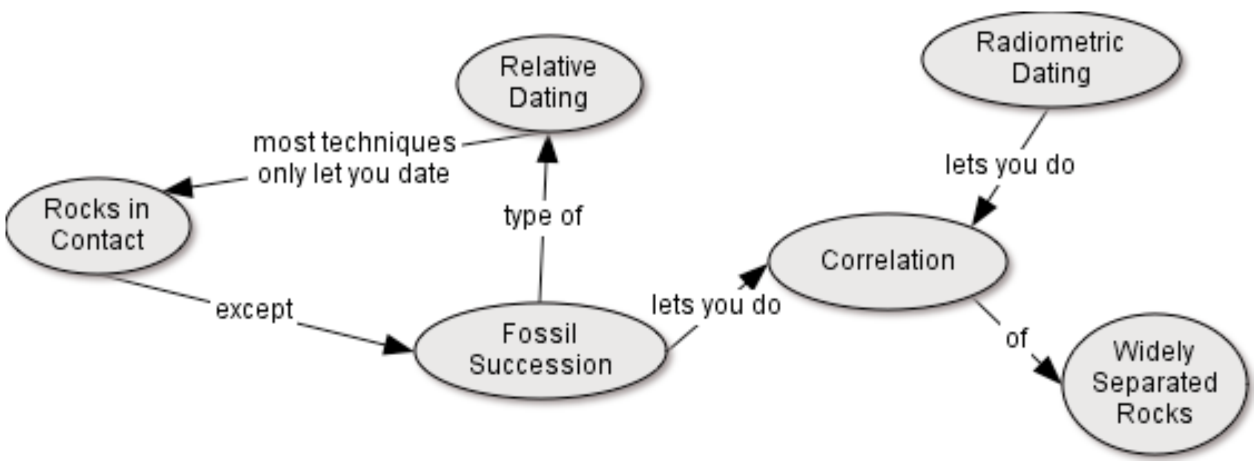
Reading Assignment

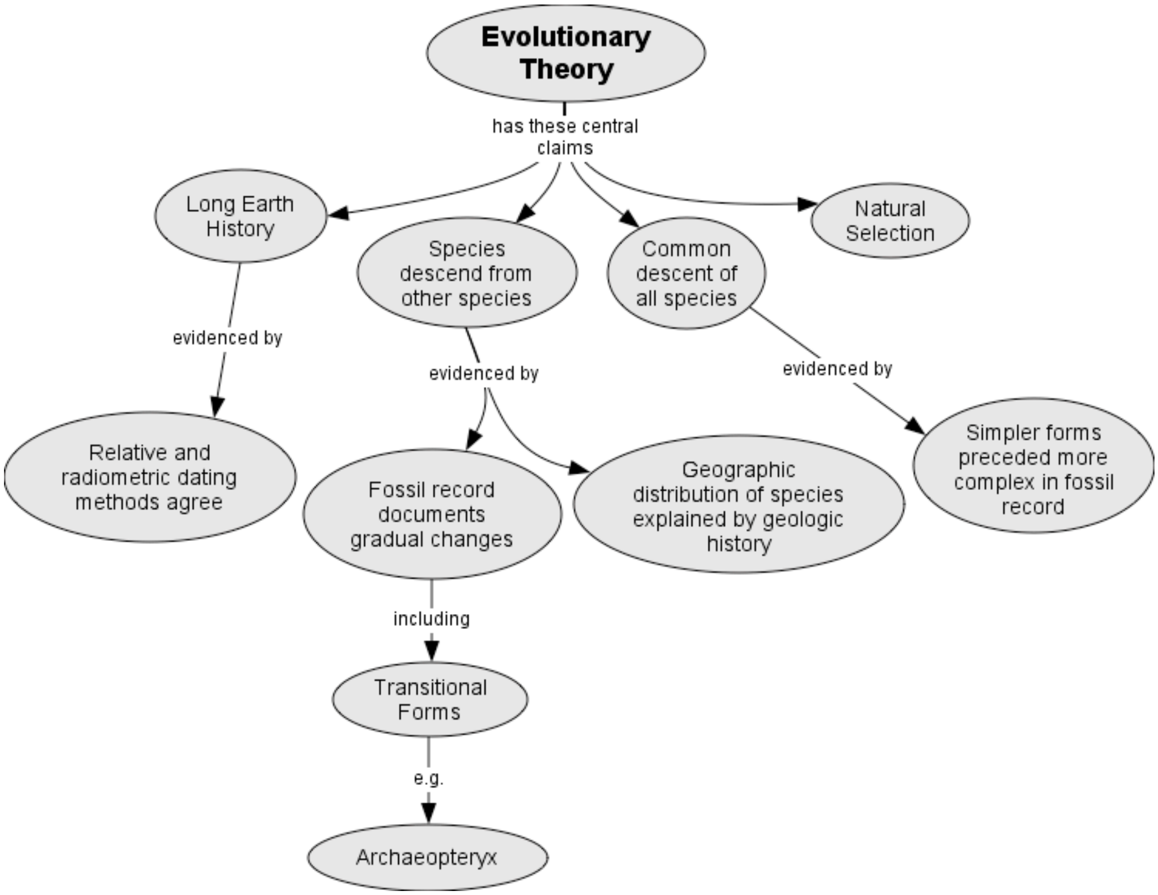
Read Ch. 8 in Lutgens and Tarbuck.

Online Quiz!

There will be an online quiz on the learning outcomes due before Period 12.


Dating Techniques
all assume the principle of
Uniformitarianism
includes these types
Relative Dating
Numerical Dating
which usually involves
Radiometric dating
which is done by measuring the ratio of these
Parent isotope
Daughter isotope
uses these principles
Original Horizontality
Superposition
Cross-cutting relationships
Inclusions
Original Horizontality
Fossil succession


Relative Dating
most techniques only let you date
Rocks in Contact
except
Fossil Succession
type of
lets you do
Correlation
Radiometric Dating
lets you do
of
Widely Separated Rocks


Evolutionary Theory
has these central claims
Long Earth History
Species descend from other species
Common descent of all species
Natural Selection
evidenced by
evidenced by
evidenced by
Relative and radiometric dating methods agree
Fossil record documents gradual changes
Geographic distribution of species explained by geologic history
Simpler forms preceded more complex in fossil record
including
Transitional Forms
e.g.
Archaeopteryx

Periods 12-13: Plate Tectonics

Learning Outcomes

After completing this unit, you should be able to answer questions related to the following.

- Give a basic outline of the Contracting Earth hypothesis, and how it explained many geologic phenomena.
- Explain what kinds of problems the contracting Earth hypothesis was facing in the early 20th century.
- Explain how Wegener came up with his "continental drift" hypothesis, and why it was not immediately accepted. (Your book is largely wrong about why it wasn't accepted.)
- Explain the basics of plate tectonic theory. What are plates? How do they move, and by what mechanisms? What kinds of boundaries are generated by plate motions? What kinds of geologic features or events occur around these boundaries?
- Be able to explain the kinds of evidence that support the theory of plate tectonics.

Terms/Concepts to Understand

Set 1
Asthenosphere
Lithosphere
Plastic deformation
Crust
Mantle
Brittle deformation

Set 2
Continental drift
Continental jigsaw puzzle
Ancient climates
Rock types and structures
Fossils
Pangaea

Set 3
Plate tectonics
Continental drift
Seafloor spreading
Ocean drilling
Hot spot migration
Paleomagnetism
Age dating
Sediment thickness
Apparent polar wandering
Magnetic reversals
Mid-Ocean ridges

Set 4
Plate boundaries
Convergent
Divergent
Transform
New crust
Subduction
Continent-continent
Collision
Partial melting
Mid-Ocean ridge
Volcanoes
Earthquakes
Deep-ocean trench
Mountain building

Set 5
Plate motion
Convection
Slab pull
Ridge push
Slab suction
Unequal heat distribution

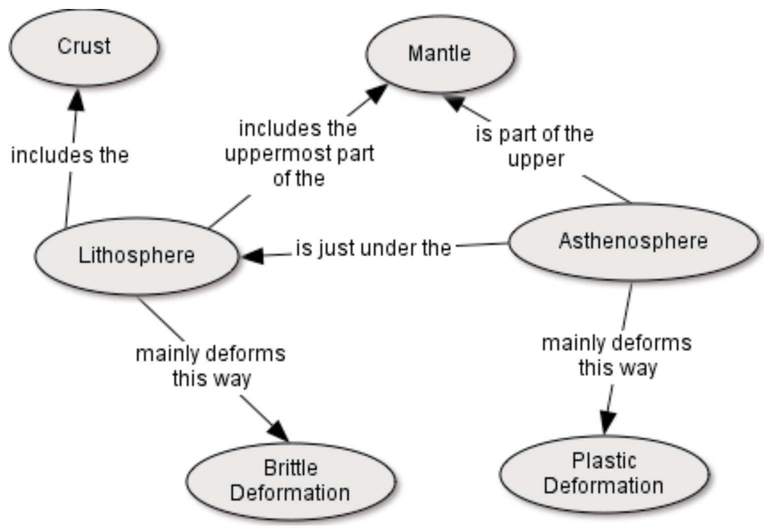
Reading Assignment

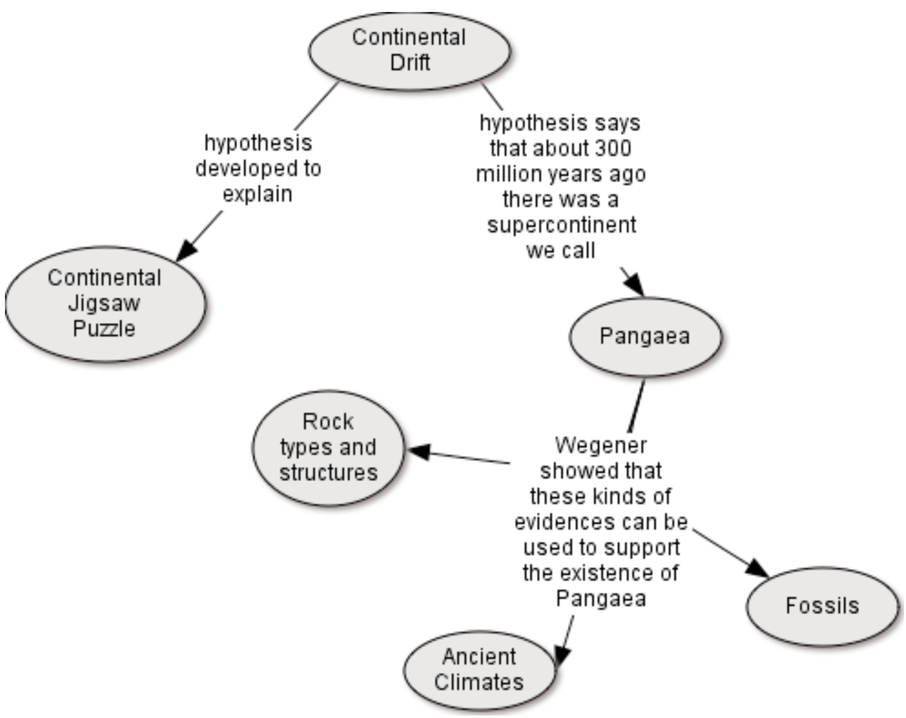
Ch. 5 in Lutgens and Tarbuck.

Online Quiz!

There will be an online quiz due 30 minutes before the next class period.

Concept Maps





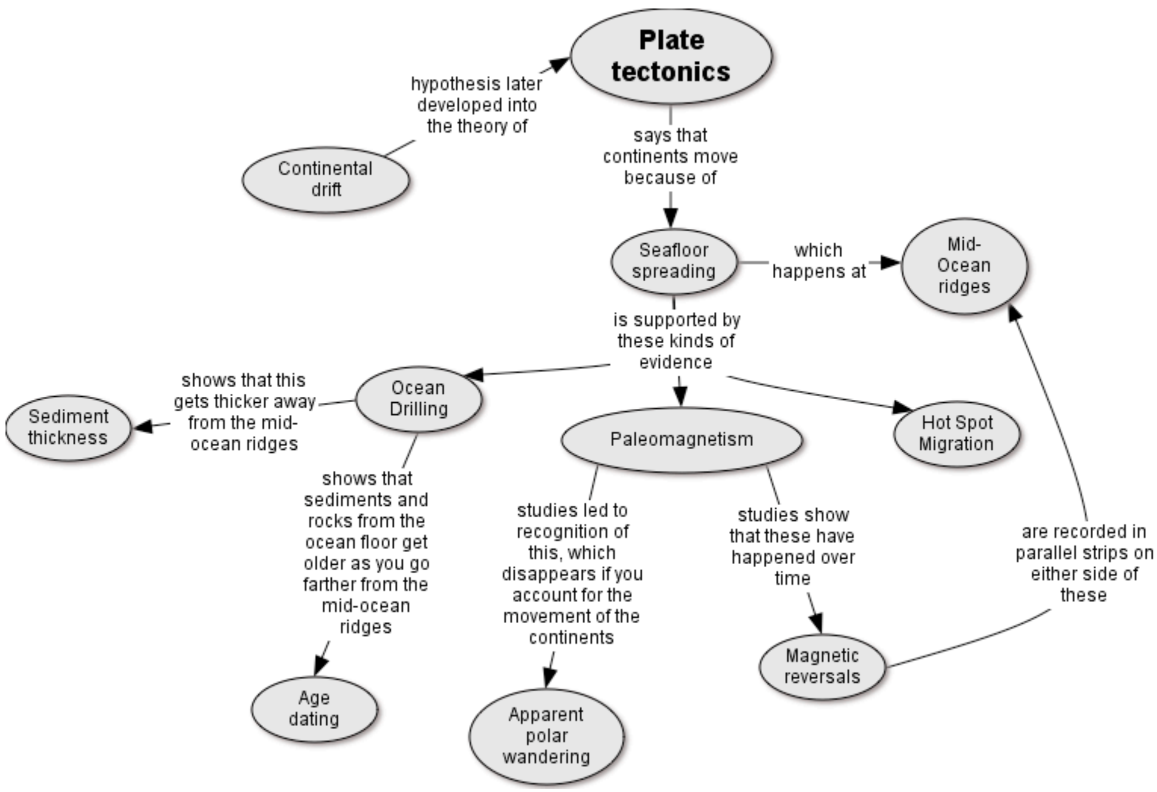


Plate tectonics
hypothesis later developed into the theory of
Continental drift
says that continents move because of
Seafloor spreading
which happens at
Mid-Ocean ridges
is supported by these kinds of evidence
Ocean Drilling
shows that this gets thicker away from the mid-ocean ridges
Sediment thickness
shows that sediments and rocks from the ocean floor get older as you go farther from the mid-ocean ridges
Age dating
Paleomagnetism
studies led to recognition of this, which disappears if you account for the movement of the continents
Apparent polar wandering
studies show that these have happened over time
Magnetic reversals
are recorded in parallel strips on either side of these
Hot Spot Migration

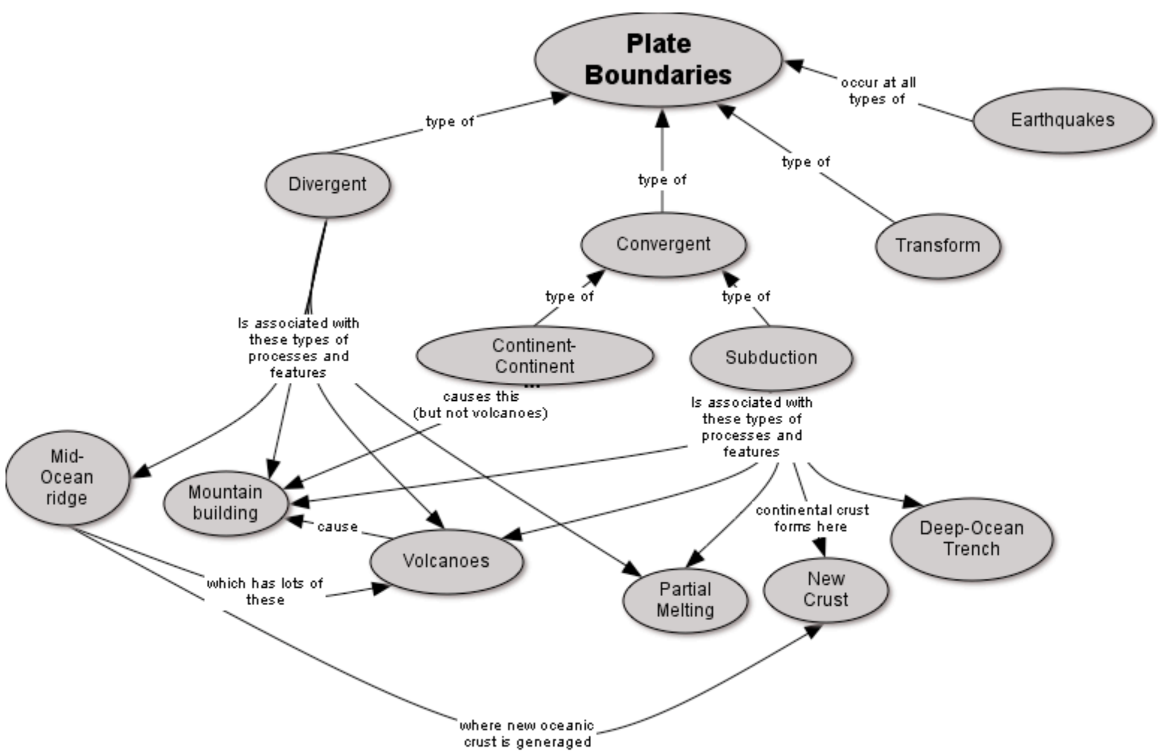


Plate Boundaries
occur at all types of
Earthquakes
type of
Divergent
type of
Convergent
type of
Transform
type of
Continent-Continent
type of
Subduction
Is associated with these types of processes and features
causes this (but not volcanoes)
Is associated with these types of processes and features
Mid-Ocean ridge
Mountain building
cause
Volcanoes
Partial Melting
continental crust forms here
New Crust
Deep-Ocean Trench
which has lots of these
where new oceanic crust is generaged

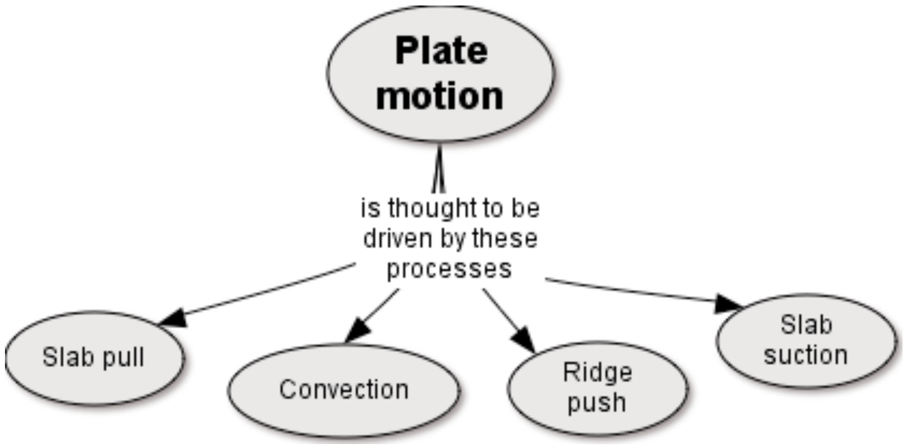


Plate motion
is thought to be driven by these processes
Slab pull
Convection
Ridge push
Slab suction

Periods 14-15: Earthquakes/Mountains

Learning Outcomes

After attending class and studying the assignment, students should be able to answer questions related to the following.

- Why do earthquakes occur, and where do most large earthquakes occur?
- Describe the different kinds of seismic waves, and how seismologists use them to tell what the interior of the Earth is like.
- How is the intensity of an earthquake measured using seismographs and the Richter scale?
- How do seismologists pinpoint the focus of an earthquake?
- Explain how mountains, folds, faults, domes, accreted terranes, and basins are formed around convergent plate boundaries.
- List and describe the destructive effects of earthquakes—liquefaction, tsunamis, etc.
- Be able to describe how a seismograph works, and how one calculates Richter scale intensities. For instance, if one earthquake was magnitude 4.5 on the Richter scale, and another was 6.5 on the Richter scale, what is the difference between the two in terms of energy released and seismogram amplitude.

Terms and Concepts to Know

Set 1
Earthquakes
Focus
Epicenter
Fault
Tectonic forces

Set 2
Earthquakes
Seismic waves
Travel through liquids
Travel through solids
P-waves
S-waves
Surface waves
Body waves

Set 3
Seismogram
triangulation
Richter scale
Seismograph
Wave velocities
Intensity
P-waves
S-waves
Focus/epicenter

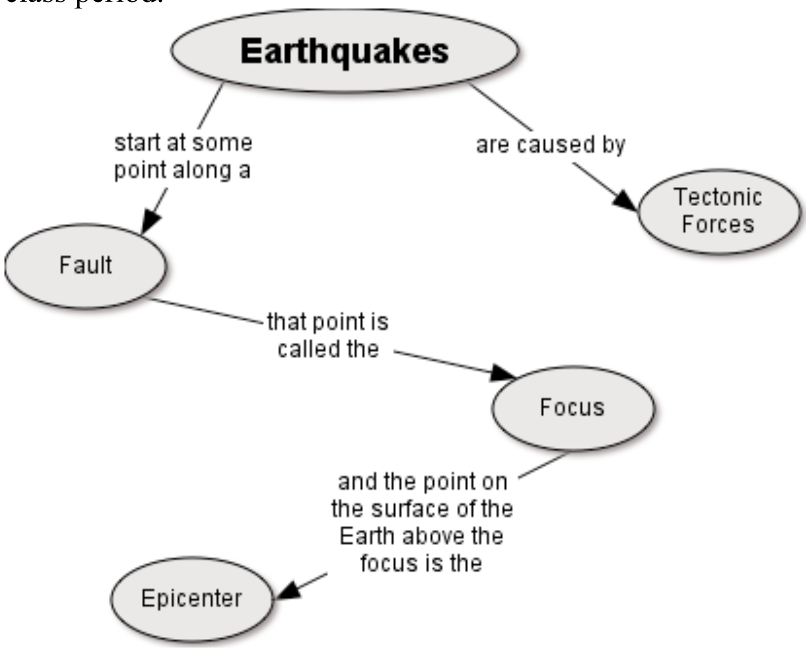
Set 4
Deformation
Fold
Anticline
Fault
Dome
Brittle
Basin
Ductile
Syncline

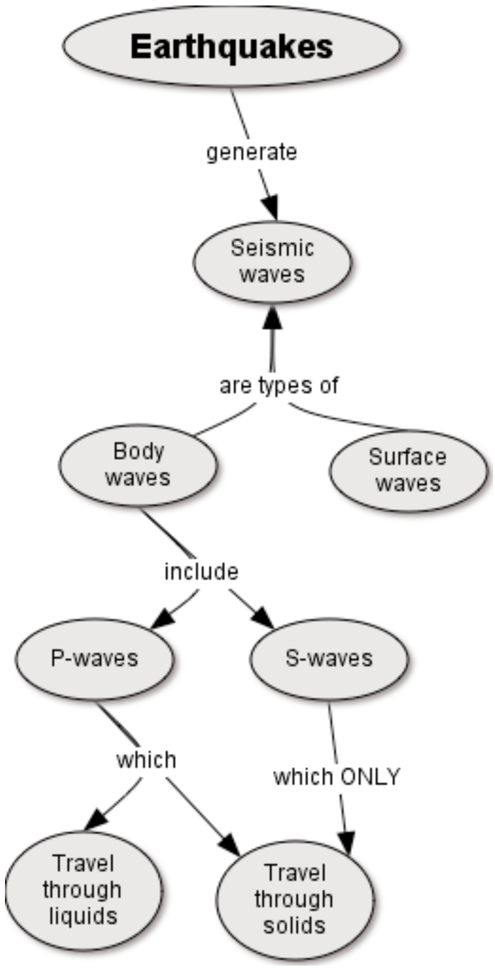
Reading Assignment

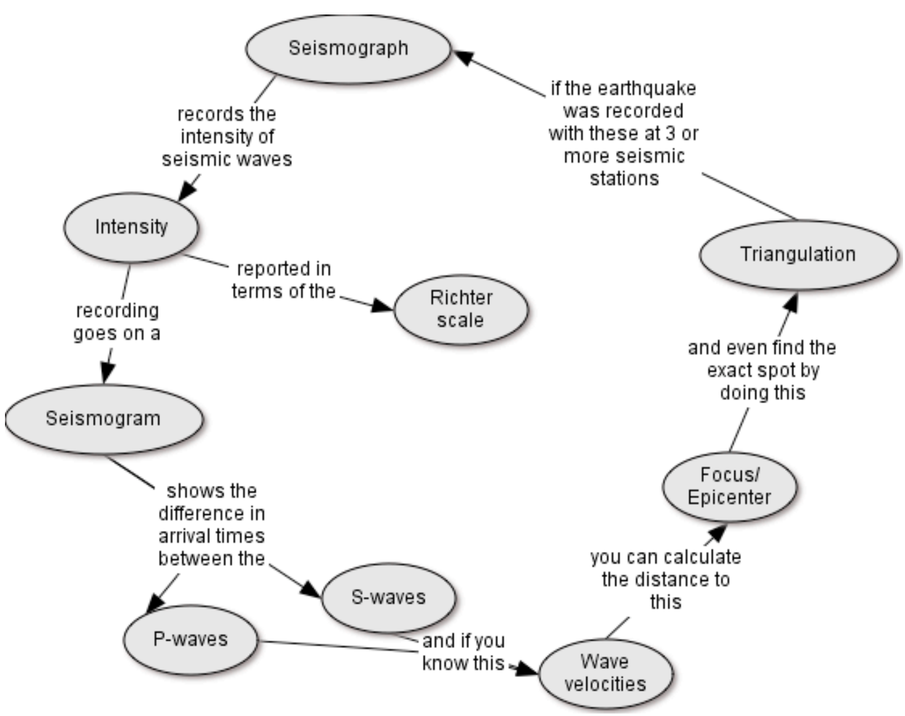
Read Ch. 6 in Lutgens and Tarbuck.

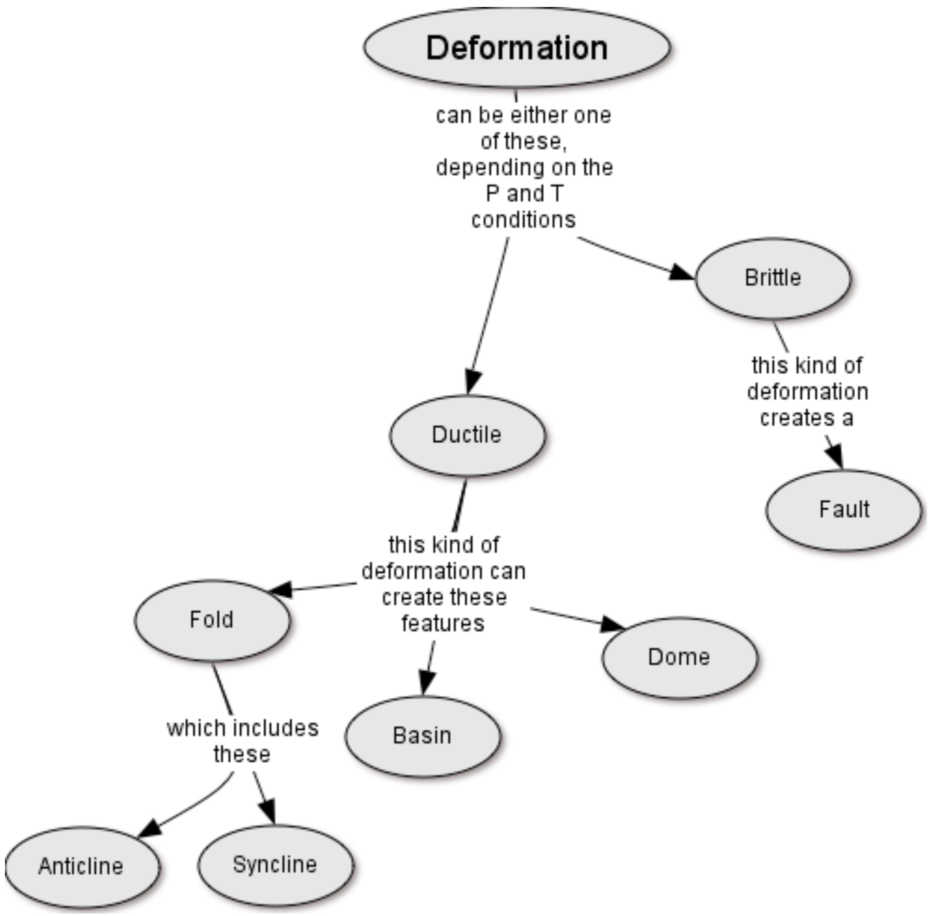
Online Quiz

There will be an online quiz that you must take by 30 minutes before the next class period.




Earthquakes
generate
Seismic waves
are types of
Body waves
Surface waves
include
P-waves
S-waves
which
which ONLY
Travel through liquids
Travel through solids


Seismograph
records the intensity of seismic waves
Intensity
reported in terms of the
Richter scale
recording goes on a
Seismogram
shows the difference in arrival times between the
P-waves
S-waves
and if you know this
Wave velocities
you can calculate the distance to this
Focus/ Epicenter
and even find the exact spot by doing this
Triangulation
if the earthquake was recorded with these at 3 or more seismic stations


Deformation
can be either one of these, depending on the P and T conditions
Brittle
this kind of deformation creates a
Fault
Ductile
this kind of deformation can create these features
Fold
Dome
Basin
which includes these
Anticline
Syncline

Period 16: Volcanoes!

Learning Outcomes

After participating in class, and studying the reading assignment, you should be able to do the following.

- Explain what controls how explosive a volcano is.
- Explain what controls magma/lava viscosity.
- Explain what Bowen's reaction series has to do with how viscous the various types of magma are.
- Describe the overall structure of different kinds of volcanoes, and explain why they turn out that way.
- Describe specific surface structures that show on or around different types of volcanoes, and explain how they form and why these specific types of volcanoes produce them.
- Explain which plate tectonic settings tend to produce the different types of volcanoes/magmas, and why?

Terms and Concepts to Know

Set 1
Low viscosity
Explosive
Med/hi silica content
Shield volcano
Composite volcano
High viscosity
Cinder cone
Lo silica content
Dissolved gases
Hi temperature
Lo temperature

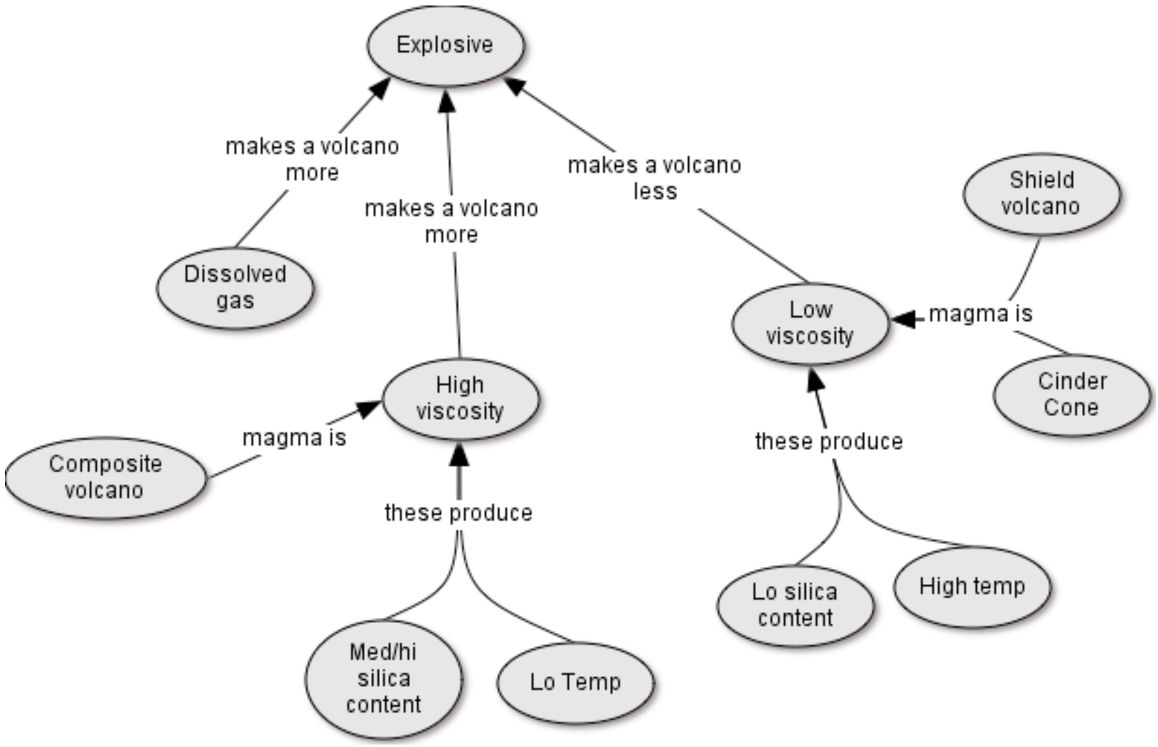
Set 2
Intermediate/felsic
Shield volcanoes
Convergent-subduction
Plate boundaries
Basaltic or mafic
Divergent
Composite volcanoes
Convergent-collision
Flood basalts
Transform
Island arcs
Volcanic arcs
Mid-ocean ridges

Reading Assignment

Read Ch. 7 in Lutgens and Tarbuck.

Online Quiz!

There will be a quiz on this unit, due 30 minutes before the beginning of the next class period.


Explosive
makes a volcano more
Dissolved gas
makes a volcano more
makes a volcano less
Shield volcano
Low viscosity
magma is
Cinder Cone
High viscosity
magma is
Composite volcano
these produce
these produce
Lo silica content
High temp
Med/hi silica content
Lo Temp

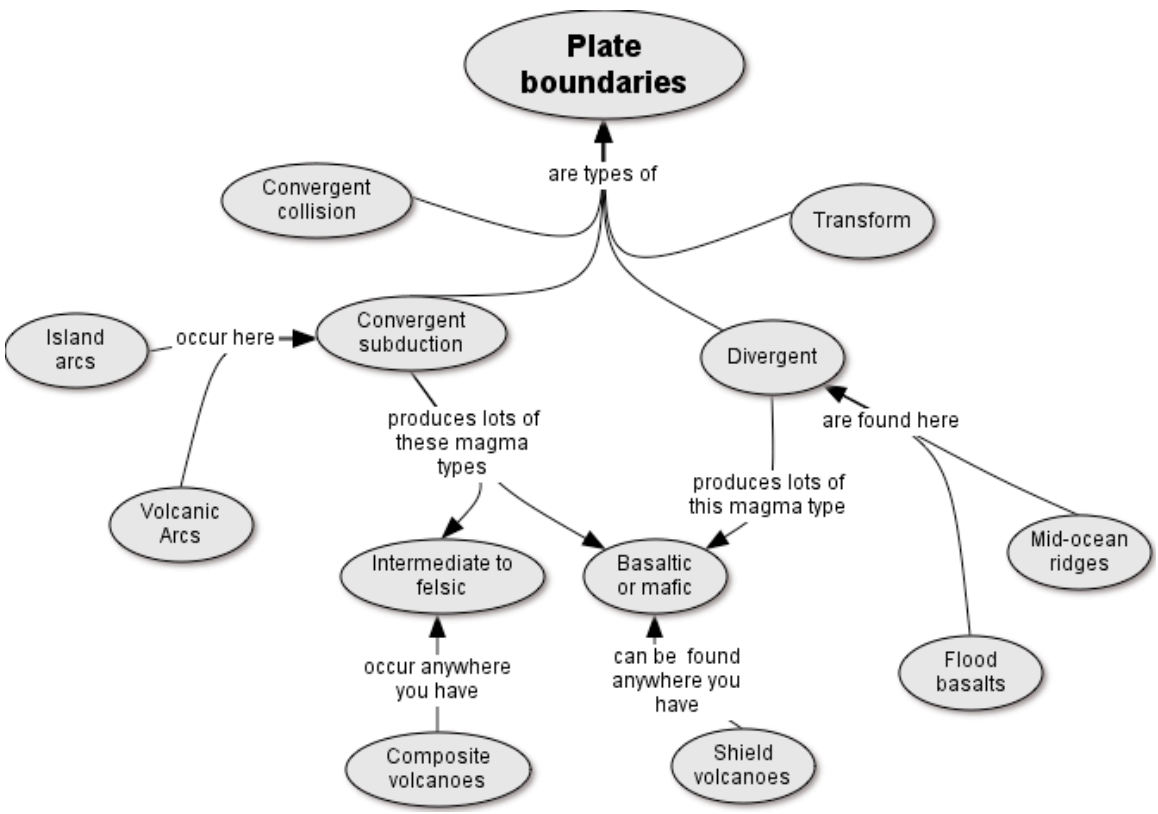


Plate boundaries
are types of
Convergent collision
Transform
Island arcs
occur here
Convergent subduction
Divergent
are found here
produces lots of these magma types
produces lots of this magma type
Volcanic Arcs
Intermediate to felsic
Basaltic or mafic
Mid-ocean ridges
occur anywhere you have
can be found anywhere you have
Flood basalts
Composite volcanoes
Shield volcanoes

Periods 18-19: Fashioning Landscapes With Water

Learning Outcomes

After participating in class, and studying the reading assignment, you should be able to do the following.

- Explain the water cycle in some detail.
- Given a description or picture of a landscape or geologic feature fashioned by water (e.g., V-shaped canyons, landslides, meandering streams, floodplains, braided streams, natural levees, deltas, incised meanders, caves, stalactites, stalagmites, sinkholes, disappearing streams, geysers, artesian wells, springs,) be able to tell a story about how it came to be that way, including the following plot elements.
    - Tectonic forces and uplift.
    - Mass wasting, erosion, and deposition.
    - Water velocity, turbulence, stream gradient, and base level.
    - Groundwater flow.
    - Dissolved gases.
    - Dissolution and precipitation of minerals.
- Be able to explain what the water table is, what it's shape is like, and why it is that way. Also, be able to tell which kinds of rock/sediment would allow for faster or slower groundwater transport.

Terms and Concepts to Know

If you can master all the terms and concepts mentioned in the Learning Outcomes, you will be in excellent shape.

Reading Assignment

- Read Ch. 3 in Lutgens and Tarbuck.

Online Quiz!

- There will be an online quiz due 30 minutes before the period 20.

Period 20: Glacial Landscapes

Learning Outcomes

After attending class and studying the reading assignment, you should be able to answer questions related to the following.

- What is a glacier? What are the two main types?
- Why do glaciers move?
- How do glaciers erode the surface of the Earth?
- What kinds of erosional features do glaciers leave behind?
- What kinds of depositional features do glaciers leave behind?
- When was the Pleistocene Epoch, and what does it have to do with glaciers?

Terms/Concepts to Know

- abrasion, alpine glacier, continental glacier, arête, cirque, crevasse, drift, drumlin, end moraine, lateral moraine, medial moraine, esker, ground moraine, hanging valley, horn, ice cap, plucking, till, stratified drift, zone of accumulation, zone of wastage.

Reading Assignment

- Read the part about glaciers in Ch. 4 of Lutgens and Tarbuck.